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THESIS

AGENT BASED SIMULATION AS AN EXPLORATORY TOOL IN THE STUDY OF THE HUMAN DIMENSION OF COMBAT

By

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March 2000

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AGENT BASED SIMULATION AS AN EXPLORATORY TOOL IN THE STUDY OF THE HUMAN DIMENSION OF COMBAT

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ABSTRACT

War is a human phenomenon and the essence of war is a clash between human wills [Ref 10]. The Marine Corps is applying complexity theory to study the human dimension of land warfare with the agent based combat simulation Irreducible Semi-Autonomous Adaptive Combat (ISAAC), developed by Andrew Ilachinski. ISAAC is designed to allow the user to explore the evolving patterns of large unit behavior that result from the collective interactions of individual agents. An urban and a desert scenario were developed to explore command and control issues with ISAAC. Utilizing a personal computer and the Maui High Performance Computer Center, approximately 750,000 ISAAC runs were completed. The data are analyzed and graphically displayed using S-Plus generated Design and Trellis plots. The ISAAC data suggest there is some optimal balance between a commander's propensity to move towards the objective and his propensity to maneuver to avoid the enemy in order to minimize time to mission completion and friendly losses. Also, the data suggest that friction can significantly influence the battlefield but a strong commander-subordinate bond can reduce the effect. In addition, this exploration demonstrates that fractional factorial designs provide almost as much information from ISAAC as full factorial designs with only a fraction of the runs.

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DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the planner.

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LIST OF SYMBOLS, ACRONYMS AND/OR ABBREVIATIONS

Agent	Most primitive entity in ISAAC
AliveB	Propensity to move towards alive blue ISAACAs
AliveR	Propensity to move towards alive red ISAACAs
AMY_S	Scenario developed by Dr. Gary Horne. See reference 6.
B(x,n,p)	binomial distribution where x is a random variable, n is the number of trials, and p is the probability of success.
ANOVA	Analysis of Variance
df	degree of freedom
EIPP	Scenario developed by Major Eipps and explored by Dr. Horne.
GOF	Goodness of Fit
InjrdB	Propensity to move toward injured blue ISAACAs
InjrdR	Propensity to move toward injured red ISAACAs
ISAAC	Irreducible Semi-Autonomous Adaptive Combat
ISAACA	Irreducible Semi-Autonomous Adaptive Combat Agent
LC	Local Commander
lcsr	LC sensor range
MEU(SOC)	Marine Expeditionary Unit, Special Operations Capable
MCCDC	Marine Corps Combat Development Command
MHPCC	Maui High Performance Computer Center
MOE	Measure of Effectiveness
MSSE	Mean error sum of squares
MSSTr	Mean treatment sum of squares
pmf	probability mass function
Rgoal	Propensity to move towards the red goal
SSE	Error sum of squares
SST	total sum of squares
SSTr	Treatment sum of squares
UPTON	Scenario developed by Major Upton and explored by Dr. Horne.
w_i	Personality weights
χ^2	chi-square
σ^2	Variance
τ	Detectable departure from the mean

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EXECUTIVE SUMMARY

War is a human phenomenon and the essence of war is a clash between human wills [Ref 10]. Because war is a violent enterprise, danger is a fundamental characteristic of it. The human reaction to danger is fear, which has a significant impact on the conduct of war. No degree of technological development or scientific calculation will overcome the human dimension of war [Ref 11].

Marine Corps warfighting doctrine encompasses the notion that uncertainty and fear will always be present on the battlefield. One can not expect to control that human dimension of war, but one must understand that it is present and function effectively with it. Marine Corps doctrine provides insight into these intangible human dimensions and incorporates these insights in the development of its leaders. Marine Corps doctrine uses leadership principles to build an effective command and control system that accepts the turbulence and uncertainty of war rather than try and control it.

The Marine Corps is applying complexity theory to study the human dimension of land warfare with the agent based combat simulation Irreducible Semi-Autonomous Adaptive Combat (ISAAC), developed by Andrew Ilachinski, of the Center for Naval Analysis. ISAAC is designed to allow the user to explore the evolving patterns of unit behavior that result from the collective interactions of individual agents. By exploring the affects of changing personalities of leaders and subordinates on the battlefield, insight can be gained in their ability to influence the action on the battlefield. An urban and a desert scenario were developed to explore the command and control capabilities of

ISAAC. Figure 1 is the urban scenario developed to explore the capabilities of ISAAC to learn about command and control in an urban environment. The desert scenario is similar in all aspects except the terrain has been removed to simulate a terrain-less environment.

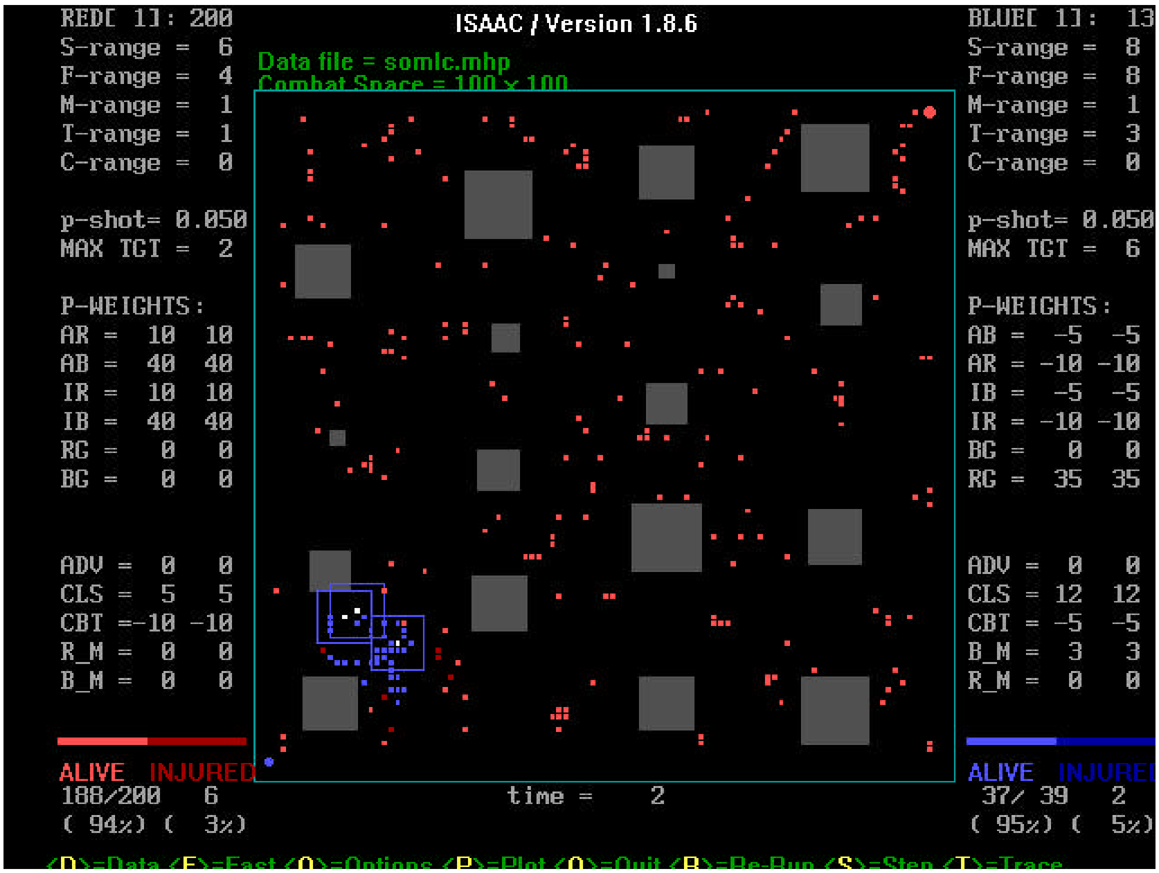

Figure 1: Urban scenario developed in ISAAC. Three squads of 13 blue forces each with a local commander are up against 200 loosely organized red forces. The blue forces are maneuvering through the urban environment to reach the red goal (upper right hand corner).

This scenario provides an opportunity to explore the Marine Corps current vision of combat and the human elements incorporated in a command and control structure in an urban environment. Red and blue dots represent the opposing forces. The red forces are greater in number, less technologically advanced, and have a loosely organized command and control structure. The red forces use personalities that are held constant throughout all the runs. The blue forces are smaller in number, technologically more advanced, and have a very structured command and control system. The blue forces are divided into three squads, each with a local commander (LC). The blue force LC personality traits and subordinate personality traits are varied in conjunction with the parameters of the command and control structure in ISAAC.

Approximately 4000 preliminary runs were completed interactively to explore many of the parameters in ISAAC. The preliminary runs served three purposes: (1) they provided an intuitive feel for the fundamental workings of ISAAC, (2) they presented areas of interest for further exploration, and (3) they collected data on measures of effectiveness unobtainable at the Maui High Performance Computer Center (MHPCC). Four areas of interest were determined for exploration using the MHPCC. The parameter sets are: (1) the local commander's command area, (2) the local commander's personality weights, (3) the blue subordinate's personality weights and (4) a mixed parameter set that consisted of a combination of interesting personality weights and sensor range parameters.

A five factor three level full factorial design and a 1/3 fractional factorial design were developed and incorporated at MHPCC. Each of the parameter sets was run with the urban and desert scenario for a combined 750,000 runs, including 100 replications per factor combination. The data were analyzed utilizing the S-Plus statistical software package and graphically displayed using S-Plus generated Trellis plots. The Trellis plots provide a visual means to study the complex interactions among the many variables.

The analysis focuses on determining which ISAAC parameters significantly influence the battlefield and which parameters do not. The urban and desert scenario results are compared to determine if the significant parameters are globally significant or scenario dependent. The fractional factorial designs were developed to provide a means of reducing the number of required ISAAC runs while still retaining the relevant information obtained from the full factorial designs. This result would allow future researchers to explore more factors simultaneously while still maintaining a manageable data set.

The LC's propensities to move toward alive blues, away from alive reds, and toward the red goal are significant in both scenarios. Losses are reduced for a LC with the following characteristics: (1) a strong propensity to move toward friendlies and move away from the enemy, and (2) assigns the mission of reaching the objective a relative degree of importance without letting the objective dominate his actions. This type of movement propensity directly relates to the concept of maneuver warfare.

The influence of the injured red forces is more scenario dependent. In the urban environment, the injured red forces influence the number of losses of the blue forces. It is still important for the LC to have a movement propensity to avoid them. In the desert scenario, the influence of the injured reds is far less. The blues can maneuver to avoid engagements and the limited ability of the injured reds in the open battlefield does not allow them to maintain a rate of advance with the blues. This type of information can influence the decision process of the LC. An area of open terrain with no obstacles might allow the LC to give less importance to the enemy injured than he would in the urban environment. It might prompt the LC to weigh more some other aspect of the battle in his decision.

Friction, that intangible element that is always present in stressful combat environments, influences the battlefield in both scenarios. Higher friction levels have a strong relationship to more blue losses. However, the interesting insight in ISAAC is that certain personality propensities interact to reduce the effect of friction. Particularly, in the desert scenario, the interaction of bond and friction was prominent. Bond is the degree of importance a subordinate places on staying close to local commander. When the friction level was high, a moderate to high level of bond seemed to reduce the effects on losses. A low bond level and a high friction level reflected increased losses in the battlefield. In both scenarios, a LC commander, first and foremost, needed a propensity to move away from the enemy. This willingness to maneuver, with a proportional propensity to move toward the red goal, minimized blue losses. In an open battlefield, a strong bond with the unit reduced losses.

The aim of command and control is not to increase our capacity to perform command and control. It is not more command and control that we are after. Instead, we seek to decrease the amount of command and control that we need [Ref 10]. How best to do so remains an open question. The results here and in other MCCDC studies provide some initial insights. The methods studied here should facilitate finding more.

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ACKNOWLEDGMENT

I would like to thank Professor Tom W. Lucas for his combat modeling insight, persistence, and guidance through this effort, from our initial discussions through the final product. Professor Lyn Whitaker was ever ready to provide her statistical insights, programming techniques, organizational advice, and S-Plus expertise to assist in my programming endeavors. I would also like to thank Professor Sam Buttery and Professor Robert Read for their statistical insight and patience in answering my never ending questions.

I would like to extend a special thanks to Dr. Brandstein and Dr. Horne at Marine Corps Combat Development Command. They provided the initial motivation for the thesis research and provided the funds necessary to perform the data collection.

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I. INTRODUCTION

"The occurrences of war will not unfold like clockwork. Thus, we can not hope to impose precise, positive control over events. The best we can hope for is to impose a general framework of order on the disorder, to prescribe the general flow of action rather than try to control each event."

Warfighting, FMFM-1

War is a human phenomenon and the essence of war is a clash between human wills [Ref 10]. Because war is a violent enterprise, danger is a fundamental characteristic of war. The human reaction to danger is fear, which has a significant impact on the conduct of war. No degree of technological development or scientific calculation will overcome the human dimension of war [Ref 11].

Marine Corps warfighting doctrine encompasses the notion that uncertainty and fear will always be present on the battlefield. One can not expect to control that human dimension of war, but one must understand that it is present and function effectively with it. Marine Corps doctrine provides insight into these intangible human dimensions and incorporates these insights in the development of its leaders. Marine Corps doctrine uses leadership principles to build an effective command and control system that accepts the turbulence and uncertainty of war rather than try and control it.

This thesis utilizes the agent based simulation Irreducible Semi-Autonomous Adaptive Combat, or ISAAC, to explore parameters associated with the human elements of the command and control in an urban combat scenario [Ref 7]. ISAAC is explored using advanced statistical designs and the data is displayed in multi-dimensional Trellis plots and Design plots. During some preliminary simulation runs, regions of the parameter space that were sensitive to change were determined. These regions were further explored to gain an understanding of how the human elements of combat fit together within ISAAC. This may allow the development of ways to exploit these sensitive regions in combat [Ref 7].

"An effective command and control system must account for the characteristics and limits of human nature and at the same time exploit and enhance uniquely human skills" [Ref 11]. The human element is difficult to study both qualitatively and quantitatively through simulation. Command and control systems are basically comprised of two elements. The first element is people and the second element is information. It is important to remember that the aim of command and control is not to lessen the role of people but to help them perform better [Ref 11]. It would be a mistake to believe that technology will solve all the problems of command and control. An understanding of the human element or dimension of command and control is essential to its effectiveness.

One of the human elements that directly influence the effectiveness of a command and control system is the personality of those involved. The personalities of the leader and of those led directly affect the effectiveness of a combat unit. There is an inseparable relationship between the leader and the led. "Leaders must have a strong sense of the great responsibility of their office; the resources they will expend in war are human lives" [Ref 12]. Individual personality dictates the different reactions to the stress of war. An understanding of the effects of differing personalities on mission objectives, particularly through the use of current standard military modeling tools, is a difficult task.

War is a system composed of semi-autonomous and hierarchically organized agents that are continuously adapting to changing environments [Ref 9]. War has all the key features of complex adaptive systems. War has combat forces that are composed of large numbers of nonlinearly interacting parts and are organized in a command and control hierarchy. There is local action, which often appears disordered, but brings about long range order. The combatants, in order to survive, must continually adapt to changing situations. Also, there is no one voice that dictates the actions of each and every combatant [Ref 7]. Since many of the key features of complex systems exist in warfare, there may be some link between complex systems and combat. Exploring this link can provide further insight into modeling the human dimension of warfare.

The Marine Corps has undertaken the study of war as a complex adaptive system in an attempt to learn more about the uniquely human qualities that affect combat situations. The Marine Corps has suggested that perhaps an application of complexity theory to land warfare includes providing an agent based simulation of combat. The agent based simulation is formulated on the concept that global behavior of a complex system originates largely from low level interactions among its primitive agents [Ref 7]. The fundamental question that arises from the study of war as a complex adaptive systems is this: can an agent based simulation be used to represent real world systems composed of individuals that have a large space of complex behaviors to choose from? ISAAC was designed to explore this question.

The Marine Corps has done some preliminary research using ISAAC [Ref 6,8]. Such works include:

Horne, Gary E. “Maneuver Warfare Distillations: Essence not Verisimilitude.” [Ref 6].

Horne, Gary. & Captain Mary Leonardi. “Trust on the BattleField.” [Ref 8]

Horne, Gary., Capt Bates and Capt. Bargeron. “Quantitative Support to Decision Makers using Agent Based Modeling of Conflicts.”

The first work [Ref 6] uses a scenario called AMY_S. This scenario is designed to gain insight into maneuver vs. attrition warfare. By increasing a unit’s propensity to move away from an enemy, the agent’s tactics took on the appearance of a maneuver type tactic vice an attrition type tactic. Varying the propensity to attract or repel the enemy yielded different results. A unit that tended to repel or move away from the enemy tended to have fewer casualties. Dr. Horne’s scenario was designed as a tool to use in the process of beginning to understand how these results occurred. In Dr. Horne’s scenario, creating a maneuver style of warfare resulted fewer casualties.

ISAAC was used in the remaining two studies to explore the effects of trust on the battlefield. The notion of trust was explored using the communication capabilities of ISAAC. Communication allows agents to pass on sensor information to similar agents and to weight the use of that information in the agent’s movement propensity. The communication was utilized as a form of trust and describes the faith and confidence one agent has in the information provided by another.

Two scenarios known as EIPP and UPTON were explored in the studies utilizing the communication ranges and weights. The scenarios differed in terrain and number of combatants. The mission success in both scenarios varied with respect to the communication levels appearing in the scenarios. The number of friendly forces killed decreased as the communication range and weight increased. However, a level was reached where the number of friendlies killed increased with further increases in the communication level. A very nonlinear, even nonmonotonic, relationship existed. The nonlinear relationship generated new areas of interest and further studies into the notion of trust on the battlefield.

These earlier works stress the purpose of ISAAC as a tool to explore scenarios. The outcomes hopefully generate new questions, fuel further research work, and assist in gaining some new understanding of the human element of combat.

The underlying dynamics of the model ISAAC are patterned after mobile cellular automata rules. ISAAC consists of a discrete heterogeneous set of individual agents that move through a lattice and can carry information as they go [Ref 7]. Each of the agents has its own characteristic properties and rules of behavior. The ISAAC agent is the most basic element of ISAAC and represents a primitive combat unit. Each agent is equipped with the following characteristics [Ref 7]:

Doctrine: a default local rule set specifying behavior in a generic environment.
Mission: goals directing behavior.
Situational Awareness: sensors generating an internal map of the environment.
Adaptability: an internal mechanism to alter behavior and /or rules.

With the above characteristics defined by the users, the scenarios can be run using an initial random or specified placement of forces.

ISAAC is designed to allow the user to explore the evolving patterns of large unit behavior that result from the collective interactions of individual agents [Ref 9]. By exploring the affects of changing personalities of leaders and subordinates on the battlefield, insight can be gained in their ability to influence the action on the battlefield. ISAAC provides an arena in which to explore the consequences of various essential characteristics of combat. This thesis uses ISAAC to explore commander/subordinate personalities and goals within a command and control structure in an urban scenario.

In this thesis, Chapter 2 gives the background motivation and the scope of this thesis. Chapter 3 gives a detailed description of the ISAAC parameters. Chapter 4 explains the analysis methodology used to explore the ISAAC data. Chapter 5 explains the results of the analysis. Chapter 6 uses the ISAAC results to examine four fundamental command and control questions. Chapter 7 provides a list of recommendations for MCCDC for improvements in the analysis and development of ISAAC.

II. BACKGROUND

In 1914, F. W. Lanchester introduced a set of coupled ordinary differential equations, now known as Lanchester equations, as models of attrition in modern warfare [Ref 3]. The Lanchester equations are the fundamental mathematical models upon which most modern theories of combat attrition are based. However, the basic Lanchester equations are applicable only when certain assumptions are made and therefore have certain limitations. These assumptions, for the basic Lanchester model, include having large homogeneous forces continually engaged in combat. Also, in the Lanchester square law equations, units are always aware of the position and condition of all opposing units [Ref 3]. Additional assumptions of the Lanchester equations include modeling combat as a deterministic process, and requiring knowledge of the "attrition-rate coefficients" [Ref 3]. Lanchester equations have provided a strong foundation for models when these assumptions and their limitations are understood. However, Lanchester equations have a drawback for they do not effectively incorporate the human factor in combat. For this reason they are not sufficient for exploring the human dimension of warfare.

A. HISTORICAL STUDIES USING LANCHESTER EQUATIONS

Several historical studies have been completed to fit campaign data using Lanchester equations. Three studies of interest, in which historical data was present, include the Ardennes campaign by Jerome Bracken, the Inchon-Seoul campaign by Dean S. Hartley and Robert L. Helmbold, and the Iwo Jima campaign by J. H. Engel. The

Ardennes campaign research results were thought to be the most successful at fitting data using Lanchester linear law equations. Although initially successful, the Ardennes campaign provided only one data point from which to assess the validity of the Lanchester equations [Ref 1]. Ronald D. Fricker soon after refuted Bracken's Ardennes findings using liner regression and data from the entire campaign with the addition of air sortie data [Ref 15]. In contrast to Bracken's previous results, Fricker concluded that neither Lanchester linear nor Lanchester square laws fit the data [Ref 15].

In the Inchon-Seoul campaign, Dean Hartley felt that the Lanchester equation components were ineffective. Hartley voiced his suspicion that, "the Lanchestarian laws do not describe actual combat." Hartley further explained that, in his view, "the data examined are insufficient for any strong conclusions" [Ref 1]. In Engel's study of the Iwo Jima campaign, he was successful in fitting the data to the Lanchester square law equations. However, the fit could not be fully validated since the data could also fit with other Lanchester equations. These results still leave many concerns regarding the applicability of Lanchester equations to model actual combat. Bracken concludes, "two-sided time histories of warfare on battles and campaigns are very rare, so Lanchester models have not been validated with historical data" [Ref 1].

By historical standards, the modern battlefield is particularly disorderly. In the past, linear formations and linear fronts described the battlefield. Today's battlefield can not be thought of in linear terms. Technological improvements in mobility, range, lethality and information gathering continue to compress time and space, forcing higher operating tempos and creating a greater demand for effective command and control [Ref

11]. The Lanchester equations do not sufficiently meet the needs for assessing the advanced warfighting concepts being explored by the Marine Corps. The current Marine Corps vision of combat is small, highly trained, well-armed autonomous teams working together, which continually adapt to changing conditions and environments in a complex battlefield [Ref 10].

B. PURPOSE AND RATIONALE

> *"So a military force has no constant formation, water has no constant shape: the ability to gain victory by changing and adapting according to the opponent is called genius."*
>
> The Art of War, Sun Tzu

The purpose of this study is to use ISAAC as an exploratory tool with which to explore and examine the developing behaviors arising from various interaction rules between commanders and subordinates. ISAAC's command and control options allow for the presence of local commanders (LCs) and for the representation of their ability to influence the action on the battlefield. The study investigates the effect of varying the personality traits of the LC and the subordinates, varying the LC's information level, varying the LC's bond with the subordinates, and varying the friction level of combat. The emphasis is on the command and control aspects of ISAAC and using ISAAC to explore the following four questions:

1. Tradeoffs exist between centralized and decentralized command and control in an urban environment. Is a centralized or decentralized command and control structure more conducive to the attainment of mission objectives?

2. When exploring the consequences of leadership personalities, what effect does varying the LC's or subordinates personalities have on the attainment of mission objectives?

3. When suggesting the likelihood of possible outcomes as a function of initial conditions, do the same significant parameters apply globally or are they scenario dependent?

4. When exploring the phenomena known as friction created by the "fog of war", how does a commander's personality affect the attainment of mission objectives when the friction between the commander and subordinates is varied?

It is important to understand that ISAAC is a tool that aids in the exploration of these questions. At this time, the Marine Corps considers the use of ISAAC to be a means of hypothesis generation for patterns of behavior that are unexpected. Although the link between ISAAC as a simulation and the behavior of the agents to the real world is being explored, no doctrinal changes are occurring based on ISAAC's results.

C. URBAN SCENARIO

Initially, I established a scenario that was motivated by a real life mission. I developed an urban scenario that was motivated by my experiences in Somalia. In early 1995, I was part of the 11th Marine Expeditionary Unit (MEU) that was involved in the withdrawal of NATO forces from Somalia. During the actual mission Marines were inserted into an urban environment while NATO forces were withdrawn from the area. At the conclusion of the NATO withdrawal the Marines were required to maneuver through the urban environment to an extraction point.

This scenario provides an opportunity to explore the Marine Corps current vision of combat and the human elements incorporated in a command and control structure in an urban environment. According to Lt. Gen. John E. Rhodes, "… that battle will take place in an environment we call the Three-Block War, Marines will be called upon to provide humanitarian assistance, separate groups of would-be combatants and engage in lethal, high intensity urban combat - all in three city blocks" [Ref 16]. In ISAAC, the urban scenario is similar to Somalia. Red and blue dots represent the opposing forces. The red forces are greater in number, less technologically advanced, and have a loosely organized command and control structure. The red forces use specified personalities that are held constant. The blue forces are smaller in number, technologically more advanced, and have a very structured command and control system. The blue forces are divided into three squads, each with a LC. The blue force LC personality traits and subordinate personality traits are varied in conjunction with the parameters of the command and control structure in ISAAC.

The scenario was run with varied initial random placement of the ISAAC agents. The time to mission completion and the number of blue agents killed were collected as data. The regions that developed interesting patterns were further explored to gain insight into the different LC personalities as applied to command and control on the battlefield and its affect on mission attainment.

D. THESIS SCOPE

ISAAC has approximately 48 parameters. To explore the effects of varying 48 parameters would be an overwhelming task. For example, a three level full factorial design requires $3^{48} = 7.98 \times 10^{22}$ runs to obtain one data point for each of the possible combinations. This number far exceeds the capabilities of all of today's computers. It also exceeds the analysis abilities of most analysts to comprehend. Even relatively simple models, such as ISAAC, contain too many parameters to run all possible combinations. Therefore to identify the prevalent indicators of LC personalities in the command and control structure, advance design of experiments were used, such as fractional factorial designs, that allow the efficient exploration of higher dimensions of a model space [Ref 2]. The Maui High Performance Computer Center (MHPCC) was made available to perform the multiple runs necessary for each parameter combination. This allows analysis on the main effects and the complex interactions that occur between them.

III. MODEL DESCRIPTION

A. MODEL OVERVIEW

This chapter explains the design philosophy of ISAAC, which includes the general penalty movement formula of the agents and describes the parameters in ISAAC. The input file for the urban scenario is given in Appendix A. It was developed and used as a base case for the statistical runs. Appendix A can be used as a reference guide as the model parameters are described.

B. ISAAC DESIGN PHILOSOPHY

1. ISAAC Overview

The battlefield in ISAAC is represented on a two-dimensional lattice of discrete sites [Ref 6]. Each site of the lattice may be occupied by one of two kinds of agents: red or blue. The initial state consists of either user-specified formations of red and blue agents or a random distribution of red or blue agents. Red and blue flags that represent goals have a user-specified position. A typical goal for both red and blue agents is to successfully reach the flag positioned in the diagonally opposite corner. ISAAC also has the capability of defining notional terrain [Ref 6].

2. ISAAC's Intended Use

ISAAC is not intended as a full system level model of combat but as a conceptual playground in which to explore high-level emergent behaviors arising from various low-level interaction rules [Ref 7]. The fundamental principle in ISAAC is not to model a specific piece of hardware but to provide an understanding of the behavioral tradeoffs involved among a large number of variables [Ref 7]. ISAAC allows the user to explore multiple scenarios with the idea of discovering and exploring the interesting emergent properties that develop from the low-level interaction rules established by the user.

3. ISAAC's Guiding Principles

ISAAC's design philosophy is based on two guiding principles: (1) keep all components and rules as simple as possible and (2) treat decisions as personality driven movement propensities [Ref 7]. The first principle refers to the effort to adhere to a relatively small set of basic combat and movement rules and to try and give the user an intuitive understanding of these rules. Therefore, the user can develop scenarios based on actual occurrences and explore the possible emergent behaviors that occur to gain further insight into battlefield developments.

The second principle is based on the fact that all decisions in ISAAC are personality driven decisions [Ref 7]. These decisions are based on a personality, which is developed randomly or by the user. The personality type attaches a degree of importance to each factor relevant to making a particular movement decision [Ref 7]. The guiding rules for each agent follow these three basic questions:

1. What are my immediate and/or long-term goals?
2. What do I currently sense in my environment?
3. How can I use what I currently know of my environment to attain my goals?

To simplify further, an individual agent cares only about moving toward or away from all other agents and his own and the enemy's flag [Ref 7]. The movement decision is based on the weights given to a particular movement propensity of the agent.

4. The Basic ISAACA

Each individual agent, called an ISAACA, exists in one of three states: alive, injured or dead [Ref 7]. Injured ISAACAs can have different personalities then when they are alive but this is not a requirement. This is a user-defined option based on the scenario developed and the behavior explored by the user. When an ISAACA transitions from alive to injured, the agent incurs some penalties on its combat abilities. In the injured state, the range at which an ISAACA can shoot an enemy is equal to one-half of the range in the alive state [Ref 7]. In the injured state, the ISAACA's movement range is reduced to the minimum possible range of one [Ref 7].

There are five ranges that are associated with each ISAACA:

1. sensor range
2. fire range
3. threshold range
4. movement range
5. communications range

These ranges are what the individual ISAACA uses to sense and gather local information [Ref 7]. The ISAACA personality determines how the ISAACA will respond to its local environment. Therefore, it is essential to have an understanding of these different ranges and how they relate to the ISAACA movement penalty formula, discussed in the following section.

The sensor range defines the maximum range at which the ISAACA can sense other ISAACAs [Ref 7]. The sensor range defines a boxed area around the ISAACA.

The sensor range can be a minimum of zero, meaning the ISAACA senses nothing, or it can be a maximum of the battlefield size.

The firing range defines a boxed area surrounding an ISAACA within which the ISAACA can engage enemy ISAACAs in combat [Ref 7]. Combat adjudication is very straightforward in ISAAC. Each ISAACA is given an opportunity to fire at any enemy that is within that ISAACA's firing range. The probability of hitting the engaged ISAACA is user-specified and is further discussed in a later section.

The threshold range defines a boxed area surrounding an ISAACA in which the ISAACA computes the number of friendly and enemy ISAACAs detected in the boxed area. The number of friendly and enemy ISAACAs detected plays a role in determining what move to make at a given time step [Ref 7]. The threshold range differs from the sensor range because the threshold range becomes a factor in determining when a user-defined set of social behavioral constraints will be activated. These social constraints are discussed in more detail in the following sections.

The movement range defines a boxed area surrounding an ISAACA that defines a region on the battlefield from which a possible move can be selected on a given time step [Ref 7]. In this version of ISAAC, the movement options are 0, 1, or 2. Movement options will be discussed in more detail in the following section.

The communication range defines a boxed area surrounding an ISAACA such that any friendly ISAACA within communication range of the centrally located ISAACA communicates the information content of its local sensor field [Ref 7]. If the communication option is enabled, each ISAACA can extend its sensor range by communicating with the other friendly ISAACAs within its communication range.

C. ISAACA MOVE SELECTION

At its movement time, each ISAACA can choose to move from its current position to any of the sites that are within the user defined movement range. The ISAACA can also remain in its current position, see the figure below.

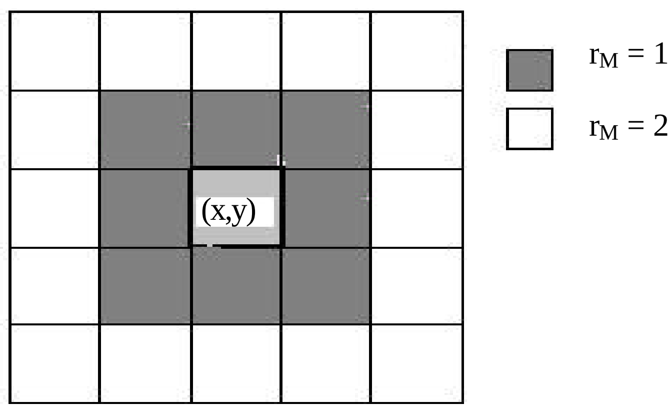

Figure 2: Set of possible ISAACA moves from its current (x,y) position. The inner shaded area depicts possible moves with a movement range (r_M) of one. The white area depicts the additional possible moves with a movement range is two.

Each site or location on the battlefield may be occupied by, at most, one ISAACA [Ref 7]. The ISAACA's personality weights are used to rank each possible move according to a penalty function. The penalty function measures the total distance that the ISAACA will be from other ISAACAs and from it's own and enemy flag [Ref 7]. The

ISAACA moves to the position that incurs the least penalty or the move that best satisfies the ISAACA's personality driven propensity [Ref 7]. The movement penalty function:

$$
\begin{aligned}
Z(x,y) = {} & w_1\, s^{-1}_{red}\, N^{-1}_{alive\ red}\ \Sigma_{alive\ red;\ i}\ d[i;(x,y)] + \\
& w_2\, s^{-1}_{blue}\, N^{-1}_{alive\ blue}\ \Sigma_{alive\ blue;\ i}\ d[i;(x,y)] + \\
& w_3\, s^{-1}_{red}\, N^{-1}_{injured\ red}\ \Sigma_{injured\ red;\ i}\ d[i;(x,y)] + \\
& w_4\, s^{-1}_{blue}\, N^{-1}_{injured\ blue}\ \Sigma_{injured\ blue;\ i}\ d[i;(x,y)] + \\
& w_5\, d_{new}\,[red\ flag;\ (x,y)] / d_{old}\,[red\ flag;\ (x,y)] + \\
& w_6\, d_{new}\,[blue\ flag;\ (x,y)] / d_{old}\,[blue\ flag;\ (x,y)]
\end{aligned} \tag{1}
$$

where: w_i's = the components of the personality weights,

$s_{red} = (2)^{1/2}\, r_{red}$, red scale factor based on red movement range r_{red},

$s_{blue} = (2)^{1/2}\, r_{blue}$, blue scale factor based on blue movement range r_{blue},

$d[i;(x,y)]$ = the distance between the i^{th} element of a given sum and the ISAACA positioned at (x,y),

N_i is the total number of elements within the given sensor range,

d_{new} = the distance computed using the given agents new (possible) move position,

d_{old} = the distances computed using the given agents old (current) position,

$\Sigma_{alive\ red;\ i}\ d[i;(x,y)]$ = the sum of the distances from the position (x,y) to all red alive ISAACA's located within the sensor range box of position (x,y) [Ref 7].

The penalty is computed for each of the possible moves and the actual move is the one that incurs the least penalty. If a tie occurs in the penalty calculation, ISAAC randomly selects the actual move from among the candidate moves making up the tie set [Ref 7]. An example of this calculation is depicted in Figure 3. Here the movement range is one and the next move is determined by minimizing the penalty that will be incurred by selecting each of the nine nearest neighboring sites. Since there are no injured red or blue agents w_3 and w_4 equal zero.

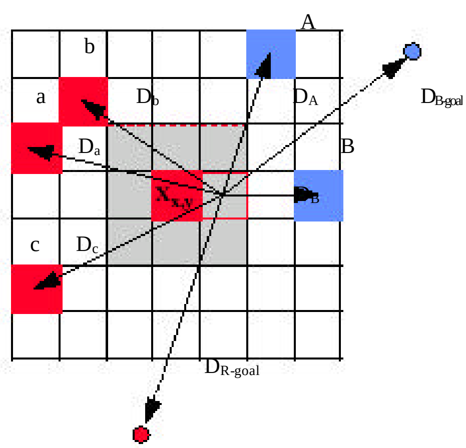

Figure 3: Sample penalty calculation. The given ISAACA (center) is calculating the movement penalty function from the possible movement location to the right of its current position.

The penalty function for Figure 3 is given explicitly by:

$$Z(x,y) = w_1\, s^{-1}_{red}\, (1/3)\, [D_a + D_b + D_c] + \quad (2)$$

$$w_2\, s^{-1}_{blue}\, (1/2)\, [D_A + D_B] + w_5\, (D_{R\text{-goal}} / D^0_{R\text{-goal}}) +$$

$$w_6\, (D_{B\text{-goal}} / D^0_{B\text{-goal}})$$

where: $D_{R\text{-}goal}$ and $D^0_{R\text{-}goal}$ are the distances from (x',y') to the red goal,

$D_{B\text{-}goal}$ and $D^0_{B\text{-}goal}$ are the distances from (x',y') to the blue goal,

D_a, D_b, and D_c are the distances from (x',y') to blue occupied sites,

D_A and D_B are distances from (x',y') to red occupied sites,

$s_{red} = (2)^{1/2}\, r_{red}$, red scale factor based on red movement range r_{red},

$s_{blue} = (2)^{1/2}\, r_{blue}$, blue scale factor based on blue movement range r_{blue},

D. GENERAL BATTLE PARAMETERS

ISAAC consists of approximately 48 parameters that the user can vary. This section gives a general description of those parameters. The intent is to give the reader a sense or intuitive feel for the parameters. This will aid in the understanding of the parameters chosen for the analysis in this thesis.

Battlefield size (*Battle_size)* defines the length of one of the sides of the two-dimensional square lattice on which the run is to be made. The user can specify any integer number between 10 and 150 [Ref 7]. The urban scenario uses a 100 for battle size for a 100 x 100 battlefield. This was held constant throughout the analysis.

Initial ISAACA distribution flags (*Init_dist_flag)* can take one of three integer values: 1, 2, or 3. These parameters allow for the initial spatial distribution of the red and blue ISAACAs. A value of one means the user defines the initial red and blue ISAACA distribution on the battlefield. If a value of two is used, the red and blue ISAACAs initially consist of random formations near the lower-left and upper-right corners of the battlefield. If a value of three is used, the red and blue ISAACAs are initially randomly placed within a square box at the center of the battlefield [Ref 7]. The urban scenario, see Figure 4, used a value of one for the initial distribution.

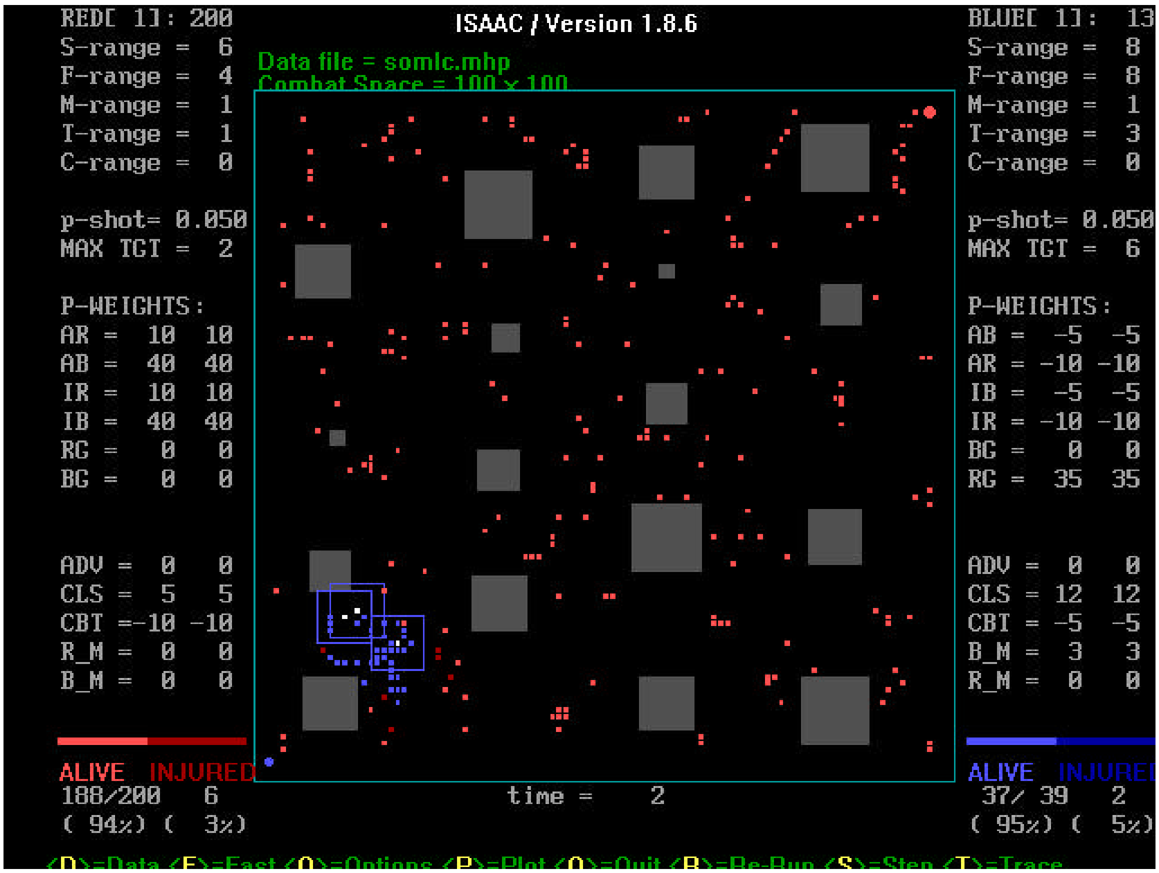

Figure 4: Urban scenario developed for use with ISAAC. The blocks represent terrain or buildings. The blue agents are attempting to maneuver to the red flag in the upper right corner. This urban scenario is also being utilized for further research in command and control aspects by the Swedish military.

Start location, *R_box_(l,w)* and *B_box(l,w)* define the length and width of the box or area containing the initial distribution of red or blue ISAACA's for each of up to ten squads [Ref 7]. The urban scenario consists of three blue squads with thirteen blue

ISAACAs each and one red squad with two hundred red ISAACAs. The box for the blue ISAACAs is in the lower left corner and the box for the red ISAACAs is the battlefield itself. Centering battlefield coordinates, *Red_cen_(x,y) and B_cen_(x,y),* provide the coordinates for the center of the box containing the distribution of red ISAACAs and blue ISAACAs for each of the squads [Ref 7].

Flag location, *B_flag(x,y)* and *R_flag(x,y),* provides the user defined location of the red and blue flags or goals [Ref 7]. For the purposes of the urban scenario, the flags are in the upper right corner for the red flag and the lower left corner for the blue flag. In this scenario, the red ISAACAs are not advancing towards the blue flag since the red objective is not to reach the blue goal but to destroy the blue ISAACAs. The blue ISAACAs advance toward the red flag to simulate traversing through an urban environment to reach an extraction point.

The *Termination* parameter specifies the termination condition that will be used during the run of the scenario. If a one is used, the run is terminated whenever any ISAACA reaches the opposing flag for the first time. If a value of two is used, the run continues until terminated by the user [Ref 7]. On a personal computer, the termination setting of two allowed the simulation to be terminated by the user when all three squads reached the red flag. However, at the Maui High Performance Computer Center (MHPCC), it was necessary to submit a specific stop time. Using approximately 4000 preliminary runs on a personal computer, simulation termination times were determined for each set of parameters that were explored. The stop times were then submitted with simulation run specifications to MHPCC.

Move_order is a parameter that allows two ways for individual ISAACA moves to occur. If using a value one, at the start of each run a random ordered list of red and blue ISAACAs is set up prior to the start of the movement. During all subsequent passes, ISAACA moves are then determined by sequencing through this list of fixed order. If using a value of two, each time the list starts the sequencing occurs in a random order [Ref 7]. The urban scenario uses a value of two for the move order. The actual movement decision formulation in ISAAC will be explained in more detail in the following sections.

Combat_flag is a parameter that specifies the maximum number of engagements between enemy ISAACAs that can occur. If a value of zero is used, there is no limit to the maximum number of possible simultaneous engagements. This means that all enemy ISAACAs within a given ISAACA's firing range will be automatically targeted for engagement. If a value of one is used then each side will be able to simultaneously target a user-specified maximum number of enemy ISAACAs per sequence [Ref 7]. These maximums are set in the maximum engagement number (*R_maxeng_num* and *B_max_eng_num)* parameter settings at the end of the input scenario. In the urban scenario, these parameters were constant: two for the red ISAACAs and six for the blue ISAACAs. This difference simulated the different technological capabilities in the two opposing forces. A more technologically advanced combat unit would be able to engage more targets.

Terrain_flag controls the use of terrain and takes either a value of zero for off or a value of one if enabling the terrain option [Ref 7]. The urban scenario has terrain and therefore the software flag is enabled. The terrain is designed to simulate a basic urban environment. The terrain was not varied in the multiple runs of this scenario. ISAAC has a Line of Sight (*LOS)* software flag that can be used in conjunction with the terrain. If *LOS* is enabled, set to one, the ISAACAs can sense through terrain. The urban scenario used the default setting of zero, thus ISAACAs were not capable of sensing through terrain. This option was not explored in this scenario but could be interesting in follow on research.

E. OTHER NON-ACTIVATED ISAAC PARAMETERS

ISAAC has several parameters that deal with fratricide and the probability that an ISAACA will hit one of its own when engaging an enemy. ISAAC also has parameters to allow for the reconstitution of killed ISAACAs after a user-defined time period. This allows for the equivalent of unit reinforcements to occur. Although more than worthy of exploration, these parameters exceed the scope of this thesis and therefore were not used in the development of this scenario.

The input format also indicates a set of statistic parameters built into ISAAC. The statistic parameters were utilized by MHPCC in their development of a core engine statistics package. For this thesis, the scenario data input file was sent to MHPCC. The statistics core engine developed by MHPCC was used to gather the appropriate statistics, which will be discussed in the analysis methodology section. The results were sent from MHPCC for analysis using the S-Plus statistics package. Therefore these software flags were not activated.

F. COMMAND PARAMETERS

1. Global Command Parameters

ISAAC was developed with the vision of having a command structure with multiple levels. Within this structure, a global commander could influence and impact the decisions made by a LC on his subordinates. At this time, the global command parameters are not incorporated into ISAAC. The software shell has been created but the logic structure has not been developed. Therefore, the global command parameters are listed in the input scenario text file, but they do not have an impact in the current version of ISAAC. At present ISAAC only has one command level; the LC and his subordinates. This command level was used in the development of the urban scenario.

2. Local Command Parameters

The local command parameters of the input data file consist of flags and variables defining the local command personality. The following description is explained for the blue forces since it is applicable to the urban scenario. However, if the red forces were to have a LC, the same flags and variables could be utilized. In the urban scenario, the red forces are assumed to be unorganized.

The blue LC flag (*Blue_local_flag*) is a software flag that indicates whether the local commander options will be used in ISAAC. When enabled or set to one, the remainder of the LC variables and flags become activated. The number of blue commander's parameter (*num_BLUE_cmdrs*) is related directly to this software flag. This defines the number of blue LCs [Ref 7]. The maximum number of LCs is ten and the entries following each LC refers to that particular LC. Each LC can have an unique set of personality parameters. In the urban scenario, the three LCs are given the same personality weights and constraints. ISAAC is not capable of recording the results with respect to the different personality parameters for each individual commander. Therefore the LC personalities remain constant to gain an insight into the collective behavior of the group.

The variable patch type (*B_patch_typ*,) describes a LC's command area. This will be explained in further detail in a later section. The command area may be partitioned into 3x3 or 5x5 blocks of smaller blocks [Ref 7]. These blocks become areas where the LC makes movement calculations to determine where the subordinates will be directed to move. A parameter of one indicates a 3x3 block and a parameter of two indicates a 5x5 block.

The patch flag (*B_patch_flag*) is a flag that regulates how a LC breaks a tie between two or more of the sub-blocks that will incur the same movement penalty calculation. If the patch flag is set to one, the LC chooses a random sub-block out of this same penalty set. If the patch flag is two, the sub-block that is chosen is the one nearest the sub-block that was previously chosen [Ref 7]. In this scenario, the patch flag is set to two. The number of subordinates for each LC is specified by the parameter *B_undr_cmd*.

Command radius (*B_cmnd_rad*) defines the radius of one of the sub-blocks that a LC's command area is subdivided [Ref 7]. The radius of a command area is determined by the formula (2r+1). Therefore a patch flag of one and a radius of one make a command area of 3(2r+1) x 3(2r+1) = 9x9 sub-blocks.

LC sensor range (*B_SENSOR_rng*) defines the blue LC's sensor range [Ref 7]. This is the range at which the LC can detect other ISAACAs. This LC sensor range can be different from that of the subordinate ISAACA sensor range.

3. Local Commander Personality Weights

ISAAC has six personality weights that can be assigned to individual ISAACAs. This means that both LCs and subordinate ISAACAs are assigned personalities. The personality weights of the LC can be different from that of the subordinate ISAACA, and the personality of a squad of ISAACAs can be different from that of other squads. However, the ISAACAs of the same squad all have the same personality weights. The six personality weights can be applied to the movement propensity of ISAACAs in their alive and injured states. These six personality weights are normalized with each other and then used in the movement calculations to determine an individual ISAACA's propensity to move toward or away from a neighboring ISAACA [Ref 7]. This movement penalty calculation, based on personality weights, was discussed previously in the ISAACA movement section.

The personality weights *w1* and w2 (w1*:alive_B and w2:alive_R,*) define an ISAACA's relative weight afforded to moving toward an alive blue and an alive red ISAACA. The weight *w3* and *w4* (*w3:injrd_B and w4:injrd_R*) define the relative weight afforded to moving toward an injured blue and an injured red ISAACA. The last two weights,*w5* and *w6* (*w5:B_goal and w6:R_goal*) represent the weight afforded to moving toward the blue goal and the red goal by that ISAACA. These weighted numbers can be any positive or negative number and are normalized with the other personality weights

[Ref 7]. A negative weight is associated with an ISAACA's propensity to move away from that corresponding ISAACA or flag, and a positive weight reflects an ISAACA's propensity of moving toward a corresponding ISAACA or flag. In the urban scenario, these personality weights are varied to examine the effect on mission objectives.

4. Social Constraints

For the LC, there are three social constraints that can be assigned. When a movement sequence occurs for a LC, the threshold range is utilized to determine if the social constraints will be applied to the overall movement penalty calculation. These three constraints are termed social constraints since they directly reflect an ISAACA's behavior in the presence of other friendly and enemy ISAACAs within the user-defined threshold range. When activated, the social constraints effect the implementation of the six personality weights discussed earlier.

Advance threshold number (*ADVANCE_num*) defines the minimum number of friendly ISAACAs that must be within the threshold range for the LC to continue moving toward the enemy flag [Ref 7]. If this number is zero, this social constraint is not enabled and the social constraint is not applied. If this number is nonzero and the number of friendly ISAACAs is less than the assigned advance number, the personality weight *w6* assigned to the enemy goal becomes –*w6*. If the number of friendly ISAACAs within the threshold range is greater then the advance number, the original user set *w6* personality weight is used.

Cluster threshold number(*_CLUSTER_num*) defines the LC's friendly minimum level. If the LC senses a greater number of friendly forces located within the threshold range, it will temporarily set its personality weight for moving toward friendly ISAACA's (*w1 and w3*) to zero [Ref 7]. Again, setting the cluster threshold number to zero does not enable this constraint.

Combat threshold number (*_COMBAT_num*) defines the conditions for which the LC will choose to move toward or away from engaging an enemy ISAACA [Ref 7]. This social constraint defines an ISAACA's willingness to engage the enemy. This constraint can be thought of as an ISAACA's combat aggressiveness. A negative combat threshold number implies that an ISAACA will have a tendency to engage the enemy even when out numbered by that assigned value. A positive combat threshold number implies that an ISAACA will not engage, if possible, unless the enemy is outnumbered by the assigned value. In the positive combat threshold number case, if the assigned combat threshold number is met, the movement personalities *w2 and* w4 are unaffected. However, if the combat threshold number is not met, *w2* and *w4* become – *w2* and – *w4*. In the case of a negative combat threshold number, once the ISAACA is outnumbered by that assigned value it will behave as above and choose to move away from the enemy rather then engage the enemy [Ref 7].

5. Command Area Parameters

The LCs have a user-defined command area, as described earlier. This command area moves with the LC throughout the battlefield and is partitioned into 3x3 or 5x5 blocks of smaller blocks. The command area blocks are decision points used by the LC to decide where to order the subordinates to move [Ref 7]. How the orders are given is discussed below. The size of the smaller blocks is equal to (2r+1) by (2r+1), where *r* is the user-defined command radius discussed earlier, see Figure 5 below.

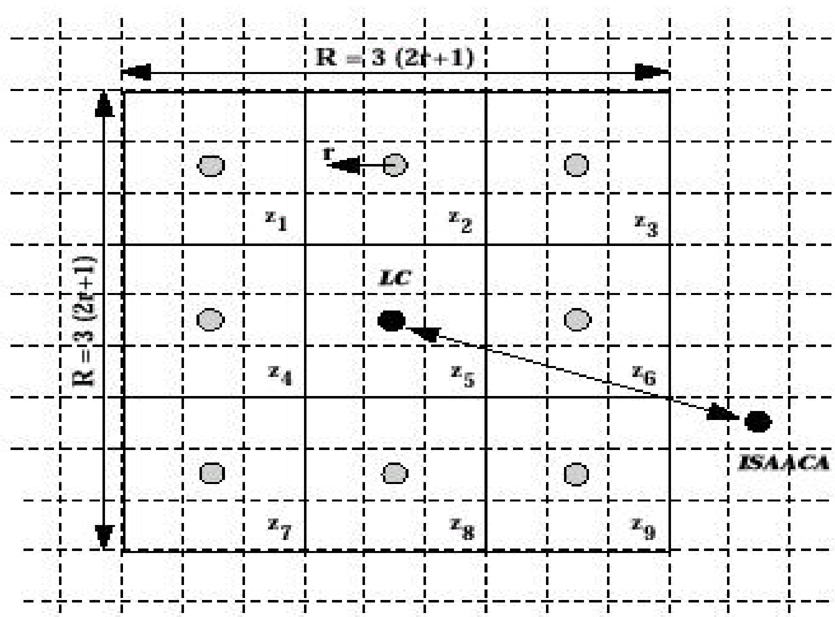

Figure 5: Command Area. With a command radius of 1, the command area is a 3 x 3 area of blocks subdivided into (2r+1) x (2r+1) or 9 x 9 sub-blocks. The LC uses the sub-blocks to direct his subordinates to a location based on his user-defined personality.

If no enemy ISAACAs are sensed in the local command area, the components of the LC's personality weight are set to zero, *w1* through *w5*. The only active component is *w6,* which is the LC's propensity to proceed toward the enemy goal [Ref 7]. When enemy ISAACAs are sensed in the command area, the local command personality that drives the movement orders given to subordinate ISAACAs is defined by four weights alpha, beta, delta and gamma. These weights describe the relative degree of importance the LC places on various measures of information contained in each block of sites within the command area. The relative information is the fractional difference between the number of friendly and enemy alive and injured ISAACAs contained in each block. The LC weighs each block of sites by a penalty weight Z_i given by:

$$Z_i = \text{alpha}\,(F_i^{alive} - E_i^{alive})\,F_T^{-1} + \text{beta}\,(F_i^{alive} - E_i^{injured})\,F_T^{-1} + \text{delta}\,(F_i^{injured} - E_i^{alive})\,F_T^{-1} + \text{gamma}\,(F_i^{injured} - E_i^{injured})\,F_T^{-1} \quad (3)$$

where: F_i^{alive} = number of alive friendly ISAACAs in the i^{th} block,

$F_i^{injured}$ = number of injured friendly ISAACAs in the i^{th} block,

E_i^{alive} = number of alive enemy ISAACAs,

$E_i^{injured}$ = number of injured enemy ISAACAs,

F_T = total number of friendly ISAACAs in the command area [Ref 7].

Then based on this penalty weight Z_i, the LC orders the subordinate to move in the direction of the sub-block with the minimum penalty. An example of such a calculation is represented in Figure 6. The minimum penalty location (x_B , y_B) determined by the LC personality movement propensity will be discussed in the overall movement penalty function in the next section.

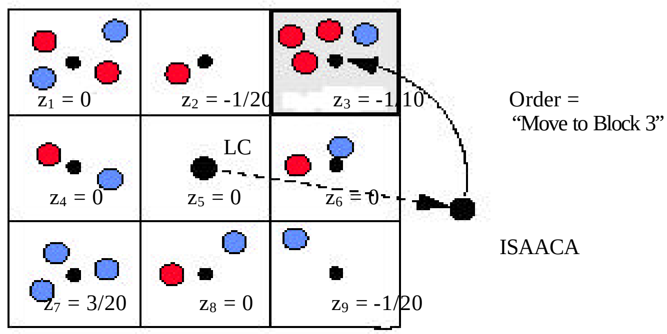

Figure 6: Example Command Area. This is a simplified 3 x 3 block in which the LC senses the friendly and enemy ISAACAs. Based on the user-specified command personality weights, the LC directs the subordinates where to move.

In general, negative alpha, beta, delta and gamma weights imply that the LC's have a tendency to send subordinate ISAACAs away from enemy dominant blocks. Positive weights imply a LC's tendency to send subordinates toward enemy dominant blocks.

G. ISAACA PARAMETERS

1. Defining Numbers and Squads

The ISAACA parameter section of the data input file consists of flags and variables defining individual ISAACA's personality weights. In many cases, the flags and parameters may be similar to some of the ones explained for the LC. In those instances, the flags or parameters will be only briefly mentioned. However, there are some differences that occur in the individual ISAACA case.

The first three parameters are basically self-explanatory *num_blues, squads* and *num_per_squad*. The first parameter defines the total number of blue ISAACAs, which is limited to 400. The second parameter defines the total number of squads, which is limited to ten. The third parameter defines the number of blue ISAACAs per squad for each of the squads [Ref 7]. In the urban scenario, there are three squads of twelve subordinates and one local commander each.

Movement range (*M_range*) defines the movement range for each of the ten possible squads. The movement range can be a zero, one, or two. A zero means the ISAACA will not move. A one means an ISAACA can move zero or one space in any direction, based on the minimum penalty function. A two implies that an ISAACA can move zero, one, or two spaces in any direction, based on the minimum penalty function [Ref 7]. In the urban scenario, a movement range of one is used and held constant throughout.

Personality is a software flag that specifies how the ISAACA's personality weights, *w1* through *w6*, will be determined. A personality of one means the user assigns the personality weights as described earlier. A personality of two means the weights of *w1* through w6 are randomly assigned. In this case, each blue ISAACA is assigned a different random weight. In the urban scenario, a personality of one is used.

2. ISAACA Personality Weights

The six personality weights for the ISAACA are identical to those described previously for the LC. However, in the ISAACA's case, ISAAC allows the user to assign a different set of six personality weights to an ISAACA when it transitions from the alive state to the injured state. This allows the user to assign different personality weights to injured ISAACAs. In the urban scenario, the personality weights are kept the same for ISAACAs whether in the alive or injured state. However, the individual weights, *w1 - w6,* were varied and will be discussed in later sections.

3. Local Commander Activated Weights

When the LC software flag is enabled, ISAAC activates two additional personality weights to the individual ISAACAs [Ref 7]. The first (*w7:B_loc_comdr*), relates to the bond that exists between a subordinate and the commander. As the LC moves about the battlefield, this user-defined weight, zero to one, influences how much weight the subordinate ISAACA affords to staying close to the commander. If the bond is one, the ISAACA's movement direction will be weighted more to stay close to the LC. On the other hand, if the bond is low the ISAACA will not give much weigh to its movement propensity in the direction of the commander.

Whether or not the *w7* weight is used depends on the LC's command area described earlier. If the subordinate ISAACA is outside the LC's command area, this weight is activated and the user assigned bond value is applied to the movement penalty function of the ISAACA. The ISAACA will then tend to move closer to the LC. If the ISAACA is already inside the LC's command area, the *w7* weight is not applied to the movement penalty function [Ref 7]. If the *w7* weight is set to zero, there is no change in the original movement penalty function.

The second added weight is *w8:B_loc_goal*. This weight is associated with the friction level on the battlefield. An ISAACA's ability to listen to the LC's orders is reflected in the friction level. This weight relates to the movement orders given by the LC based upon the LC's decision calculations in the command area [Ref 7]. As the friction level increases on the battlefield, the ability of a subordinate to listen to the orders of superior's decreases. Therefore, when the LC gives a movement order, the user assigned ISAACA's ability to listen is used to weight the ISAACA's movement based on the movement penalty function. A high ability to listen to the LC's orders is a $w8 = 1$ and no ability to listen to the LC's orders is a $w8 = 0$.

When the LC flag is enabled, the movement penalty function is:

$$Z = Z_o + W_7\,(X_{LC},Y_{LC}) + W_8\,(X_B,Y_B) \tag{4}$$

Where: Z_o = general movement penalty function.

(X_{LC},Y_{LC}) = LC's (x,y) coordinates on the battlefield.

(X_B,Y_B) = the (x,y) coordinates of the move to block determined by the command area parameters of the LC.

4. ISAAC General Parameters

This group of software flags and variables are best described as general parameters since they vary in their applications. The *defense_flag* is a software flag that regulates the notional defense option. If the *defense_flag*=0, this option is not enabled. When this flag is enabled, *defense_flag*=1, two additional parameters are defined. These are *alive_strength* and *injured_strength* [Ref 7]. These parameters define the defense strength of the alive and injured ISAACAs. In the default case, when the defense flag is not enabled, if an ISAACA is hit once, it changes from an alive state to an injured state.

If hit again, it will go from an injured state to a killed or removed state. However, this option allows the user to alter the default settings to allow more then one hit before an ISAACA transitions to another state [Ref 7]. In the urban scenario, the default setting is used and this option was not explored further.

Sensor range (*S-range*) defines the ISAACA sensor range, as explained earlier, for each of the possible ten ISAACA squads. The sensor range can be any positive integer value. If a value of zero is used, then the ISAACA will not sense anything around itself [Ref 7]. Also, squads can have different user-defined sensor ranges. In the urban scenario, the sensor range of the blue ISAACAs is set at eight and the sensor range of the red ISAACAs are set at six. This difference is to simulate a greater technological advantage in obtaining local enemy information for the blue forces.

Firing range (*F*_range) defines the firing range for each of the 10 possible ISAACA squads. Firing range can take on any positive integer value. If firing range is zero the ISAACA is unable to shoot [Ref 7]. In the urban scenario, the blue ISAACA squads are given a firing range of eight and the red ISAACAs are given a firing range of six. This difference was established, as described in sensor range, to simulate a technological advantage by the blue forces over the red forces.

The communication flag (*Comm_flag*) is a software flag that regulates the communication option for the blue and red ISAACAs. If the communication option is enabled, ISAACAs communicate with other friendly ISAACAs within a given communication range (*comm_range*) as set by the user. This communication consists of the passing of the location of enemy ISAACAs. This, in turn, affects the movement penalty function for each ISAACA since more enemy information becomes available. The weight afforded by using this information is assigned by the user variable *comm_weight* [Ref 7]. The communication weight is usually a number between zero and one, however, numbers greater then one can be used when the user desires to assign more importance to information gained through communication then directly sensed by the ISAACA [Ref 7]. In the urban scenario, the communication flag is not enabled. Marine Corps Combat Development Command in Quantico, Virginia has been doing extensive research using the communication option. Therefore, this was not considered a focus of this thesis, which deals predominantly with the personality differences between commanders and subordinates.

5. ISAACA Social Constraints

Many of the social constraints for the individual ISAACAs are the same as they were for the local commander. The one difference is that subordinate ISAACAs can have different social constraints in an injured state. The ISAACAs have a set of social constraints when they are in the alive state. They also have a set of social constraints when they transition to the injured state. In the urban scenario, the social constraints are set to be the same. However, the user could use this option to explore other areas of interest.

The movement flag (*movement_flag*) is a software flag that controls the use of the social constraints. If this flag is set to zero, the social constraints will not be enabled. If the flag is set to one, the social constraints become part of the movement penalty function [Ref 7]. In the urban scenario, the movement flag is set to one and the social constraints are utilized. However, these parameters were not varied in the course of this analysis but could easily be used to further expand the research.

In the ISAACA social constraints, the threshold range, advance number, cluster number and combat number are identical to those described earlier in the LC's social constraint section. In the urban scenario, the cluster and combat social constraint parameters are utilized. The cluster for the blue forces is set at twelve to allow squads to stay together but not have a propensity to move closer to other squads. The red forces are given a cluster of five. This is meant to simulate the red force as loosely organized units in a urban environment. The combat parameter for the blue forces is set at negative five. This means a blue ISAACA will engage an enemy even if outnumbered five to one. The red forces are given a combat parameter setting of negative ten. This is designed so that red forces, which are greater in number but less technologically advanced, are more willing to engage the blue forces on their home soil.

ISAAC has a set of parameters for advance, cluster and combat that can be set to randomly choose parameter settings with a minimum and maximum level. To have this option enabled, the personality flag, discussed earlier, must be enabled [Ref 7]. Once enabled these three parameters are randomly chosen in each successive run between the minimum and maximum level. This option is not enabled in this urban scenario.

The ISAACA social constraints have three additional parameter settings that are not available to the LC. These are minimum distance to friendly forces (*B_B_min_dist*), minimum distance to enemy forces (*B_R_min_dist*), and minimum distance to enemy goal (*R_R_min_dist*) [Ref 7]. The parameters are simply user defined minimum distances. Therefore, if exceeded, the ISAACA's movement penalty function takes this into account and attempts to make the necessary weighted adjustments to correct the distance. ISAAC does this by defaulting to or negating the appropriate *w1, w3* or *w2, w4* personality weight in the penalty movement formula to obtain the desired movement propensity. These parameters can also be set to be different for ISAACAs in the injured state. In the urban scenario, a minimum distance between blue forces is set to be three. This was to simulate a trained structured unit attempting to keep some dispersion of forces while maneuvering through the city. This parameter was held constant throughout the exploratory research done in this thesis.

6. Combat and Engagement Parameters

The probability of a hit on a targeted enemy (*shot_prob*) defines the blue ISAACA's single-shot hit probability. This represents the probability that a targeted enemy ISAACA is hit [Ref 7]. In the urban scenario, the shot probability for the blue and red forces is .05. This probability is kept constant since, in an urban environment, weapons effectiveness can be seriously degraded by the surrounding structures. With the focus of this thesis being command and control, the aspect of weapons effectiveness in an urban environment is left for future exploratory work.

The maximum enemy engagement number (*B_max_eng_num*) defines the maximum number of simultaneously targetable enemy forces by friendly forces. This parameter correlates directly to the combat flag parameter discussed under the General Parameters section. If the user wishes to define this maximum number of engagements, the combat flag is enabled and the user sets the appropriate number at this time. If the combat flag is not enabled then this parameter simply has no maximum level [Ref 7]. In the urban scenario, the blue forces can engage a maximum of six red targets in range. The red forces are only allowed to engage two blue targets. This is to simulate a more technologically advanced unit with the ability to engage more targets and a unit with a superior command and control structure.

IV. ANALYSIS METHODOLOGY

This chapter explains the methodology used to explore ISAAC. In this chapter, the measures of effectiveness (MOEs) and statistical designs used to evaluate the significance of the parameters in ISAAC are explained. This chapter also explains how sample sizes are chosen and the statistical techniques used in determining the significance of the ISAAC parameters. Also, this chapter explains some limitations imposed by the MHPCC and the affect the limitations had on the statistical designs.

In the urban scenario, the mission of the blue friendly ISAACAs is to maneuver through the urban environment to their objective, the red goal. There are two measures of effectiveness used to examine the success of the mission and provide some insight into the four basic command and control questions discussed in the Purpose and Rationale section. The first MOE is time to mission completion and the second MOE is number of blue ISAACAs killed during the mission.

A. TIME TO MISSION COMPLETION (MOE 1)

The time to complete a mission is often a critical mission element that influences the decision process of a commander. If a mission is deemed time critical then the LC's mission priorities often change. The loss of human life is never taken lightly. Therefore, an acceptable tradeoff between time requirements in a mission and the loss of human life must be found. The command and control structure in ISAAC has several areas that directly influence the time to mission completion. Four of the areas explored are the size of LC's command area, the LC's sensor range, the bond that exist between the LC and his subordinates, and the friction level that is created by the fog of war in stressful environments. The command and control structure in ISAAC is used to gain insight into the relationships among these factors and the MOEs.

1. Areas Explored for Time to Mission Completion

The size of the command area directly relates to the friendly and enemy information the LC can sense. This is reflected in the movement decision or guidance given to the subordinate ISAACAs. The ISAACAs use this movement guidance in their movement penalty function. The user has the capability to change the size of the command area. This can be done through the patch type and command radius parameters. If the decision area of the local commander is increased, thereby increasing the level of information, does this influence the time to mission completion? The size or patch type and the command radius are varied and the time to mission completion was analyzed.

The LC sensor range influences the movement decisions of the LC. The LC's movement directly influences the subordinate ISAACA's movement decisions. The LC sensor range levels are varied. They ranged from 6, less then the subordinate ISAACAs, to 18, greater then the subordinate ISAACAs.

The remaining two areas explored for MOE 1 are the bond that exists between the LC and the subordinate ISAACAs, and the friction level that occurs in combat. In ISAAC, bond is the subordinate ISAACA's tendency to remain close to the LC as the LC maneuvers. If the bond is strong the LC has more direct influence over the subordinate

ISAACA's movement. This relationship exists because the subordinate ISAACA uses more weight in its movement formula to stay close to the LC.

The bond relationship is also explored in conjunction with the friction level in the scenario. The friction level is the subordinate ISAACA's ability to listen to the movement guidance given by the LC. The bond and friction levels are varied and the time to mission completion is examined.

2. MHPCC Limitation for Time to Mission Completion

The MHPCC has some limitations in the present statistical package in respect to time to mission completion. The original version of ISAAC was developed without the ability to have a LC. Therefore, the statistic gathering software was written to record the time the first ISAACA arrived at the objective. However, with the development of the urban scenario consisting of three squads and three LCs, when one squad arrives at the objective, the other two squads may still be maneuvering through the urban environment. It would not be accurate to assume that the arrival of the first squad to the objective is equivalent to mission completion time. Therefore, to gain some insight into which parameters are significant in influencing time to mission completion, the simulation runs for MOE 1 were conducted interactively, one at a time, at a personal computer-vice multiple runs at MHPCC. The parameters and results are then compared. The simulations can be manually stopped when all three squads reached the objective using a personal computer. Approximately 4000 simulation runs were completed varying the appropriate parameters. The results are examined to determine which parameters influenced the time required for all three squads to reach the objective.

B. BLUE ISAACAS KILLED (MOE 2)

The second MOE is the number of blue ISAACAs killed in the completion of the mission. This MOE allows the use of the full computational capabilities of the MHPCC. Based on the preliminary research, four sets of parameters were selected. The preliminary runs also provided an opportunity to gain an intuitive feel for the effects of the parameters on the MOEs. This resulted in several errors being identified and corrected in the MHPCC statistical package during the initial command area runs. These sets of parameters were chosen to provide insight into the four basic questions discussed earlier.

1. Command Area Parameter Set

This set of parameters is the primary means by which ISAAC is used to explore the fundamental concepts of centralized and decentralized command and control. For the LC, command and control is the means by which a commander recognizes what needs to be done and is responsible for appropriate actions [Ref 11]. In some instances, command and control occurs concurrently with action being taken in the form of real time guidance in response to a changing situation. The Command Area Parameter set included the four parameters, alpha, beta, delta, and gamma, associated with the command area of the LC. These four commander personality weights describe the relative degree of importance the LC places on various measures of information contained in each block of sites within his command area. The four parameter weights are varied from a negative one, LC's tendency to send subordinate ISAACAs away from enemy dominated blocks, to a positive one, LC's tendency to send subordinate ISAACAs toward enemy dominated blocks.

The positive and negative settings are interpreted as a centralized command and control structure for the LC. The LC directly influences the movement decisions of the subordinate ISAACAs by giving guidance based on his personality. When the parameter weights are zero, the LC is providing decentralized command and control to the subordinates. The LC's guidance is neutral and the subordinate ISAACAs must rely on the other elements in the command and control structure to make movement decisions. So, with the LC's command area parameters at zero and therefore having no direct influence, the LC provides a form of decentralized control based on his movement decisions through the bond parameter.

Using MOE 1, the centralized and decentralized command and control structures are explored to provide insight into which is more effective in an urban environment. A similar desert scenario was developed using a no terrain environment. The four command personality weights were varied in a similar manner. Once again, the command structure is explored and the results of both scenarios are compared.

2. Personality Parameter Sets

Two sets of parameters are chosen to explore the possibilities of the second basic question, which concerns the consequences of differing LC personality weights and the resulting differing subordinate ISAACA personality weights. The two parameter sets are LC Personality Weights and the Blue ISAACA Personality Weights sets. The specific parameters chosen for the LC and the subordinate ISAACA's are: propensity to move toward alive blues (w1), propensity to move toward alive red (w2), propensity to move toward injured blue (w3), propensity to move toward injured red (w4), and the propensity to move toward the red goal (w6). The LC parameters were varied while the subordinate ISAACA personality weights were kept at a base level. Then the subordinate parameters were varied while the LC parameters were kept at a base level. Due to the limitations imposed by MHPCC, the LC parameters could not be varied simultaneously with the blue subordinate ISAACAs. This would have been more beneficial in the analysis of the effects. Using ISAAC, the parameters that are significant in effecting the number of blue ISAACAs killed are identified. With the parameters identified the question is then; could an intuitive feel be gained for those significant parameters and could they be related to actual combat conditions? Finally for those parameters that unexpectedly were or were not significant; could the results be reasonably explained by current combat theories?

3. Mixed Parameter Set

This final data set focuses on the elements that are sometimes referred to as intangible elements of war. Intangible elements, such as bond and friction, are explored in this parameter set. The mission drive or the desire to reach the objective is also explored. In ISAAC, the mission drive can be expressed as the LC and subordinate ISAACA's propensity to move towards the goal. These parameters are varied to learn about the relationship between the LC and the subordinate ISAACAs mission drive. The question explored is as follows: how does this desire to accomplish the mission effect the number of casualties of war when the LC's or ISAACA's drive is aggressive or more conservative?

A final factor explored in this data set is the influence of increased information to the LC. The LC sensor range allows the LC to sense the friendly and enemy situation around him. The intent is to gain insight on how this information level effects the number of casualties. The significant parameters are also determined.

C. FACTORIAL DESIGNS

With the parameter sets chosen, an experimental design was necessary to compare the many variables. Factorial designs were chosen. Factorial designs work well when experiments are performed to measure the effects of one or more variables on a response [Ref 2]. The"effect" of a factor means the change in the response as the factor level moves from the low level to the high level. The "response" is the time to mission completion or the number of Blue ISAACAs killed. Separating the variable comparisons into main effects and interactions is a convenient and powerful method of analysis in cases where the interactions are small relative to main effects [Ref 2].

There are other compelling reasons why factorial designs seemed well suited for the exploration of the ISAAC model. Factorial designs are effective in exploratory work where the object is to determine quickly the effects of each of a number of factors. Also, factorial designs allow the testing of interactions in all combinations [Ref 2].

1. 3^n Design

For the exploratory analysis to be conducted in this work, a 3^n factorial design was selected as the most appropriate. Using a 3^n factorial design, one can examine a nonlinear response surface. Throughout the many preliminary data runs, there seemed to be non-linear behaviors in many of the variables in ISAAC. A 3^n design allows the examination of quadratic curvature in the response.

a. MHPCC Statistical Design

The ISAAC program incorporated at MHPCC is designed to allow five parameters to be varied at a time. Therefore, this led to a 3^5 design used in the four-parameter sets. Therefore, five parameters or factors were varied at three levels each. In cases such as the command parameters, which consisted of only four parameters, the fifth parameter was simply a dummy variable left unchanged throughout the data runs.

b. Power Calculations

Two types of data are gathered in the multiple ISAAC runs. The data are the time to mission completion and the number of blue ISAACAs killed. In determining which factors are significant, one needs to test the hypothesis of whether the difference in effects are caused by chance variation or whether the differences are the result of real differences in effects [Ref 7]. The null hypothesis is usually that the observed differences are the result of chance. The alternative hypothesis is that the differences are the result of real differences in effects.

There are two types of errors that can occur in hypothesis testing. The errors are called a type I error and a type II error [Ref 7]. A type I error is incurred when the null hypothesis is true, but rejected. The probability of a type I error can be controlled by a user-specified significance level (α).

A type II error occurs when the effects are different, but the null hypothesis is not rejected [Ref 7]. The type II error can be thought of as a measure of how sensitive the analysis is when the alternative hypothesis is true. The probability of a type II error is β. The power of a test is defined as 1-β. The power of a test is the probability of correctly rejecting the null hypothesis given that the alternative hypothesis is true. For fixed α, the probability of a type II error can be decreased by increasing the number of observations or sample runs. Power calculations are done to determine the number of samples needed to reduce the probability of a type II error to an acceptable level.

In a set of unknown true means (μ_i), where the response variables have a variance (σ^2), the power does not need to be determined separately for each different configuration of the unknown true means. Power depends on the μ_i's and the σ^2 only through $\sum\mu_i^2/\sigma^2$ [Ref 2]. For a fixed value of $\sum\mu_i^2/\sigma^2$, β decreases as the sample size on each treatment increases. Once the variance is estimated and the level of departure from the null hypothesis the user wishes to be detected is specified (through $\sum\mu_i^2/\sigma^2$), the sample size requirements can be determined. The detectable departure level is called τ and is the sensitivity level that the user wishes to set in the hypothesis test, where $\tau = \sum\mu_i^2/\sigma^2$.

Hand computations of β and sample size determination can be difficult. Therefore, S-Plus was used to construct a set of curves from which β can be read. These are called power curves where:

$$\text{Power} = 1 - \beta \tag{5}$$

Using the curves displayed in Figure 7, it can be seen that to have a power of .9 and the ability to detect departures from the null hypothesis, number of blue ISAACAs killed, of .5 to .75 requires a sample size of roughly 100. To achieve this power for departures of 1 or more a sample size of 50 is sufficient. Appendix B contains the S-Plus code for the power calculations.

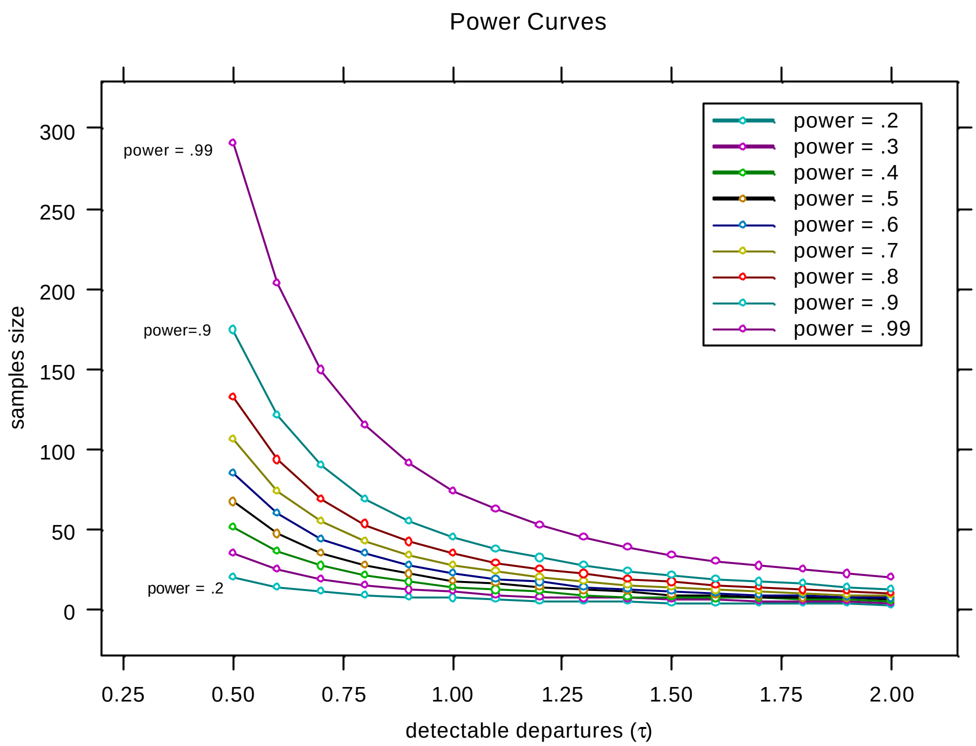

Figure 7: Power Curves for a 3^5 full factorial design used for sample size determination. The change in the mean value that the user wants to detect (t) is on the x-axis. The number of sample data points is on the Y-axis. The power of the design can then be determined.

c. Replicate Runs

A 3^5 full factorial design contains all 243 combinations of the factor levels. The 243 combinations allow us to estimate all of the interactions. However, when only one data point is recorded for each of the possible combinations there are no degrees of freedom remaining for estimating the standard error. In the case of the four parameter sets, an additional set of replicate runs was performed with a different initial seed at the start. Each data point is an average of 100 runs with different initial starting seeds. Using the average of the 100 runs is necessary so that the computational capabilities of S-Plus are not exceeded. This replicate run allows for the estimation of residuals, which are used to check the necessary constant variance and normality assumptions, which are discussed in the following section. Therefore, with a full factorial design of 100 interations and a replicate run, the number of simulation runs for the four parameters sets equaled:

$$3^5 * 100 * 2 * 4 = 194{,}400.$$

2. Fractional Factorial Design

The number of runs required in a 3^n full factorial design increases geometrically as n increases [Ref 2]. When n is large, the required samples are very large. However, the desired information can often be obtained by using only a fraction of the full factorial design [Ref 2]. A one-third fractional design, 3^{5-1}, requires only eighty-one runs, one-third of the 243. A fractional design comes at the cost of confounding, i.e., confusing, some of the high level interactions with main effects and other interactions. Confounding means the effects of the confounded interactions can not be estimated separately. Therefore, a fractional design must be developed that does not confound the main effects or interactions of interest.

The intent was to compare the data from the full factorial design to the fractional factorial design and determine if the same conclusions would be reached. This is valid if high level interactions are negligible. In a 3^n experiment, each main effect has two degrees of freedom (df), corresponding to the linear and quadratic effects. The two factor interactions have four dfs, giving a total of $2n^2+1$ df's [Ref 2]. Using the ISAAC model, the intent was to see if the main effects and the first order, two term, interactions were the most significant in explaining the results. This would allow the higher order interactions to be discarded as noise. Also, it would allow a simplification of the model and make the understanding of the parameters and interactions more intuitive to the user. The simplification also requires less processing.

Three fractional design simulations were run for three of the parameter sets for a total number of runs of:

$$3^{5-1} * 100 * 3 = 24,300.$$

With the main effects and first order interactions being most important, a fractional design was developed in which none of the main effects and the first order interactions were confounded with eachother.

a. Resolution V Design

With the number of first order, two term, interactions increasing so quickly, it was necessary to develop a resolution V design. A resolution V design is one that does not confound main effects and two factor interactions with each other, but does confound two factor interactions with three factor interactions and higher [Ref 2]. See reference 2 for further details on generating a 3^{5-1} fractional design of resolution V.

3. Desert Scenario Test Data Set

Once significant parameters were identified, it remained to see if these results might generalize to other scenarios. A comparison data set was necessary. To create a comparison data set, the urban scenario was modified with the removal of the terrain. The four parameter sets were then run using the same factors at the same levels. The goal was to determine if a certain level of predictability could be attained based on the significant parameters in the urban scenario when compared to the significant parameters in the open battlefield. Also, the intent was to determine if certain parameters tended to be globally significant or if they were scenario dependent. The results reflected some interesting insights into which parameters were significant throughout and which were scenario dependent. See the chapter V Results.

D. NORMALITY ASSUMPTIONS

Several different analysis techniques were utilized to explore the data obtained from the four parameter sets. The techniques included Analysis of Variance (ANOVA), Yates' Algorithm, Tukey's method of multiple comparisons and Trellis and Design plots utilizing special S-Plus features. The response data, concerning blue ISAACAs killed, was also examined to see if it could be fit to a known distribution. Specifically, the response data was fit to a Poisson distribution with reasonable success.

The majority of the analysis techniques used in the study of ISAAC involve the assumption of the data being approximately normally distributed. In all the data sets, more than enough runs were conducted to invoke the Central Limit Theorem by averaging the 100 runs. The ANOVA procedures, in conjunction with Yates' Algorithm, are based on the assumptions of normality and constant variance. Analysis techniques using Tukey's method of multiple comparisons are also based on the assumption of normality and constant variance. Therefore, the data from the four different data sets were explored to test if normality assumptions with constant variance could be justified.

1. Analysis of Variance

If it could be assumed that the model was adequate, and that the errors were normally and independently distributed with constant variance, then by using the F-tests, the effects of the parameters could be judged as significant or not [Ref 2]. Using S-Plus [Ref 13] to perform the statistical work, the ANOVA was carried out. However, as soon as an analysis of the residuals was carried out for these data, it was immediately obvious that the model considered above was not adequate. This can be seen in Figure 8 below. Figure 8 is a plot of the residuals against the fitted values of the variables aliveB, aliveR, injrdB, injrdR and Rgoal. The standard deviation increases as the fitted value of blue ISAACAs killed (bkilled) increases. The residual analysis suggests that the variance is a linearly increasing function of bkilled [Ref 2].

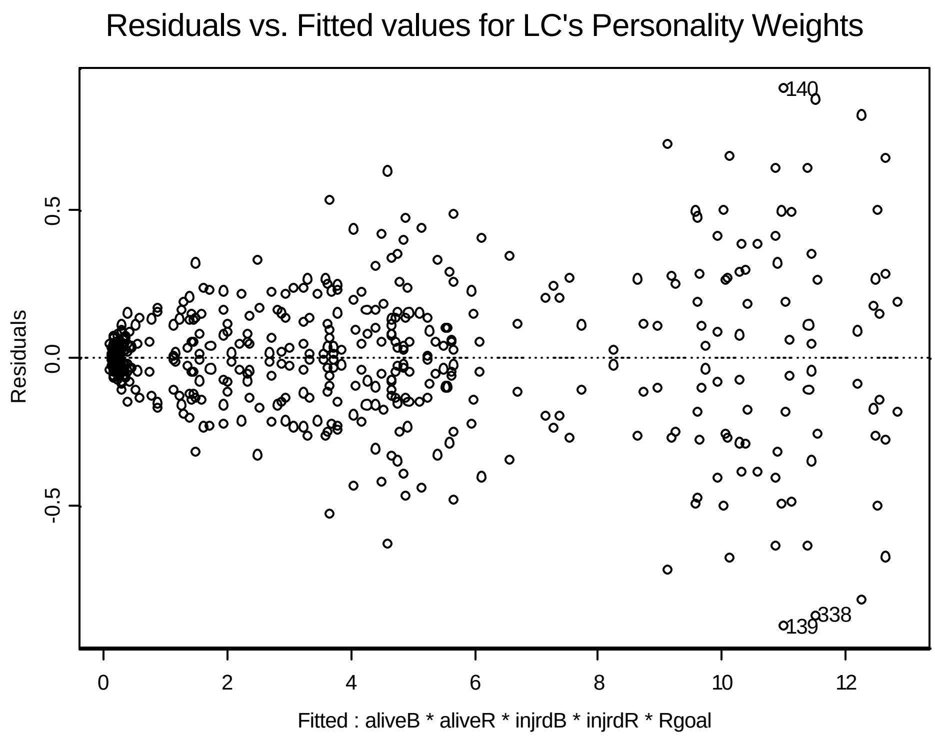

Figure 8: Residuals vs. Fitted Values of the variables. The funnel shaped plot strongly suggests that the standard deviation increases as the mean value increases.

The residual analysis suggests that, contrary to assumption, the variance is a function of the mean of the blue ISAACAs killed. This means that a suitable transformation must be applied to the data to allow the use of the equal variance assumptions. Since the ISAACAs are either killed or not killed, the data is essentially binomial in nature. Therefore, a suitable power transformation is the square root of the response. Once the power transformation was applied and the diagnostic work completed, it was obvious that the equal variance assumption was applicable to the data. The residual plots are displayed in Figures 9 and 10 and reflect the effectiveness of the square root transformation.

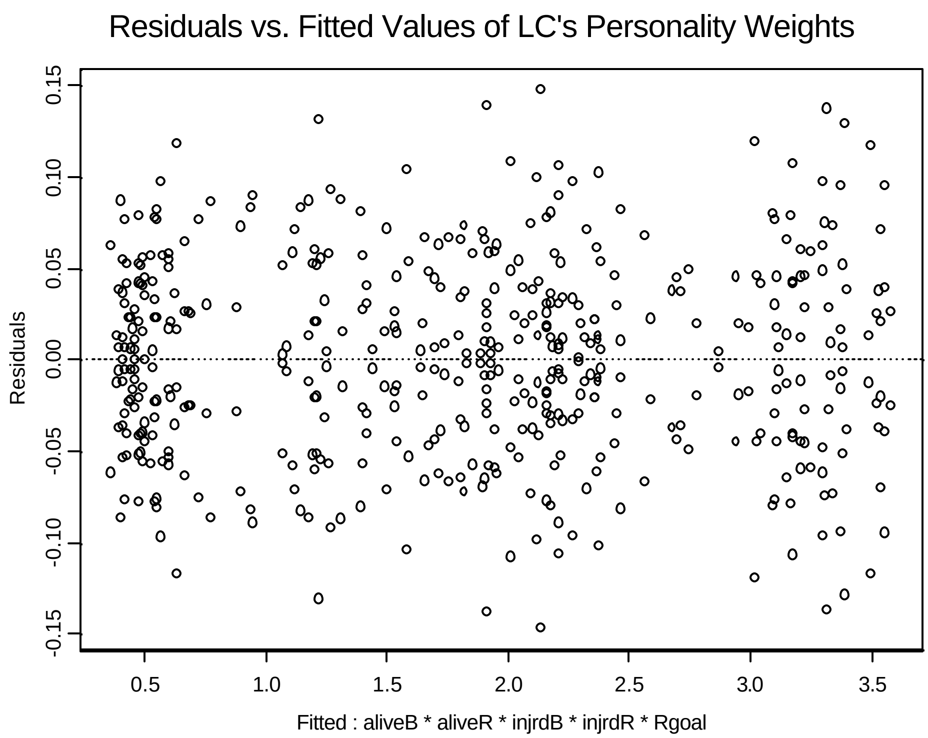

Figure 9: Residual vs. Fitted Values of the LC's Personality Weights. The data has been transformed using a square root power transformation.

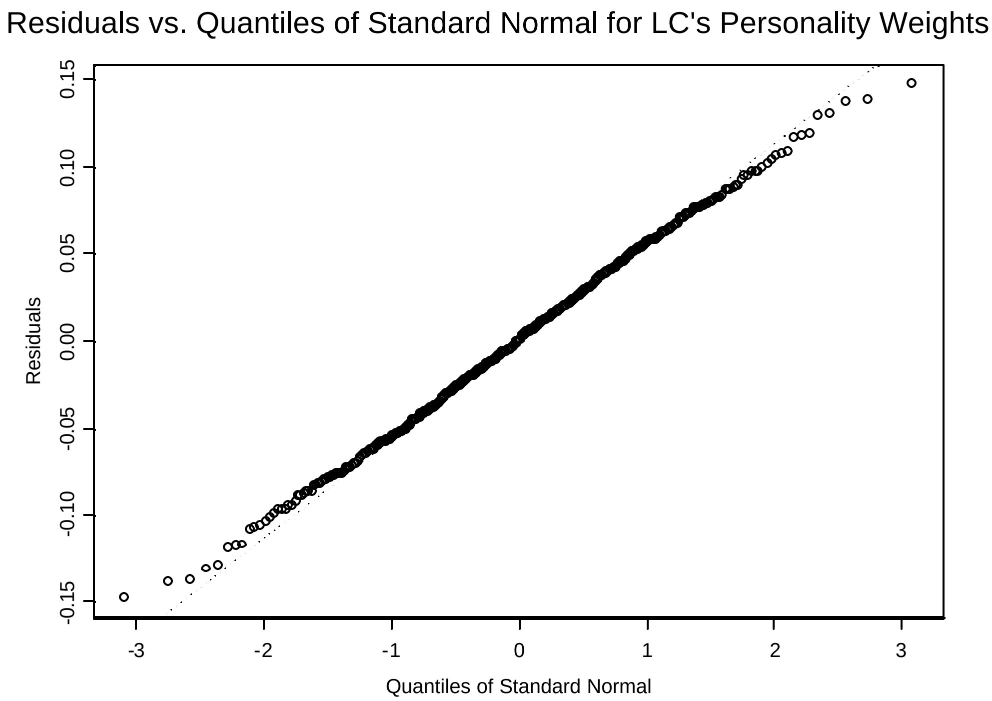

Figure 10: Residual vs. Quantiles of a Standard Normal. The data has been transformed using a square root power transformation.

A similar transformation using the square root power transformation was necessary for the Mixed Parameters set. The Command Area Parameter set and the Blue ISAACA Personality Weight Parameter set did not require transformation. After the transformations were completed, the data behaved reasonably well when compared with the normal distribution with constant variance and the appropriate assumptions could be accepted and the analysis continued.

2. Significant Parameters

Analysis of variance procedures are used very often for simultaneous F tests. This type of ANOVA tests the null hypothesis, which states that different levels of a factor have no effect on the response variable [Ref 2]. A null hypothesis such as this is made for each factor in the analysis. ANOVA reveals that the levels of a factor have a statistically significant impact on the value of a response, but this method does not show which levels make a difference.

a. F-Test

We will use an F-test to see if the measures of the treatment combinations are all the same or not. Specifically, we will test the null hypothesis (H_o), all of the treatment combinations are the same, versus. the alternative hypothesis (H_a), all of the treatment combinations are not the same. The F-test determines a p-value. The p-value has the following interpretation: the p-value is the probability of seeing data this or more extreme if the null hypothesis is true. If the p-value is less then the significance level, H_o is rejected. Otherwise, H_o is not rejected [Ref 2].

b. Yates' Algorithm

The ANOVA tables generated by S-Plus provide information concerning which variables are significant. However, the ANOVA tables do not break down which levels of the variables are significant. In a 3^5 factorial design it may be possible for the linear effect, the quadratic effect or both to be significant. A means was necessary to determine this. Also, in many of the data sets it was not possible to count the higher order interactions as noise since there appeared to be some significant interaction. However, in many cases the higher order interactions were significant with very small sums of squares and many df's. In all the data sets, the five term interactions proved insignificant. However, in the four and three term interactions, it was suspected that that only one or two df's were significant out of the sixteen df's for four term interactions, and eight df's for three term interactions. Using an algorithm developed by F. Yates, the ANOVA table could be broken down into the linear and quadratic effects, and into to single df's for the higher order interactions [Ref 2]. Yates' Algorithm was not available in any of the available statistical packages. The algorithm was therefore coded into EXCEL for use in this thesis. Once Yates' Algorithm was implemented using EXCEL, it was shown that the higher order interactions were in fact significant in only a very few of the higher order interactions. Using this information the assumption was made that the higher order interactions were essentially noise and the analysis focused on the main effects and the first order interactions. This assumption greatly simplified an already complex model by allowing the significant parameters to be broken down into main effects and first order interactions.

3. Tukey's Method

Sometimes a better understanding of the uncertainty associated with an estimate of many means is provided by a set of confidence intervals [Ref 2]. The information provided by a set of confidence intervals includes that given by significance tests. Tukey's procedure allows us to simultaneously test all pairwise means for significant differences with a specified overall type I error rate. The S-Plus statistical software package was utilized to perform and display these calculations.

Tukey's method of multiple comparisons was used when exploring MOE 1 for several areas of ISAAC. These areas included LC's command area size, LC sensor range, bond and friction. Using MOE 1 in comparing mission completion objectives, Tukey's method provided insight into which parameters had a significant effect on the time to mission completion.

E. FITTING THE RESPONSE TO A POISSON DISTRIBUTION

The number of blue ISAACAs killed can be seen as the sum of several nearly independent binomial experiments. Each ISAACA has a small probability of getting killed. Hence, it was thought that the number of blue ISAACAs killed might fit a Poisson distribution.

A random variable X is said to have a Poisson distribution if the probability mass function (pmf) of X is:

$$P(x; \lambda) = e^{-\lambda}\lambda^{x} / x! \qquad \text{for some } \lambda > 0,\ x = 0,1,2\ldots \qquad (6)$$

The rationale for using the Poisson distribution is provided by the following proposition. Suppose that $X \sim b(x;n,p)$, then as $n \to \infty$ and $p \to 0$ in such a way that $np \to \lambda > 0$, then $X \to p(x;\lambda)$ [Ref 14]. According to this proposition, in any binomial experiment in which n is large and p is small, $b(x;n,p) \cong p(x;\lambda)$ where $\lambda = np$. As a rule of thumb, this approximation can be accurately applied where n is large, p is small and $np \geq 5$ [Ref 14].

Using the S-Plus chi-square (χ^2) Goodness of Fit (GOF) procedures, the distribution of the number of Blue ISAACAs killed is examined for a particular level and combination of parameters. The hypothesized distribution was the Poisson distribution. The chi-square GOF uses a one-sample test that examines the frequency distribution of n observations (n = 100 here) grouped into k classes. Observed counts (c_i) in each class are compared to expected counts (Ci) for the hypothesized distribution (with the esitmated sample mean $\lambda = x$) with test statistic χ^2 [Ref 12].

$$\chi^2 = \Sigma^k_{i=1} (c_i - Ci)^2 / c_i \tag{7}$$

For some specified significance level α, the null hypothesis is rejected if $\chi^2 > \nu$ for which $p(\chi^2 > \nu) = \alpha$ under H_o [Ref 12]. Where ν is the α - level critical value of a χ^2 random variable with $k - 1 - 1$ degrees of freedom.

F. TRELLIS PLOTS

To display the multi-dimensional ISAAC output data in an effective and insightful manor, the Trellis plots provided by S-Plus are used. Trellis arose from the need to study complex interactions among many explanatory variables acting on a response [Ref 12]. The major feature of Trellis displays is the multi-panel conditioning where each row and column conditions on a different variable. This means of data visualization enhances the analysis of the traditional ANOVA table and Tukey's method by allowing us to look simultaneously at more than three dimensions. The power of this visualization will become readily apparent in the following section.

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V. RESULTS

"War is the realm of uncertainty; three quarters of the factors on which action in war is based are wrapped in a fog of greater or lesser uncertainty….The commander must work in a medium which his eyes cannot see; which his best deductive powers cannot always fathom; and which, because of constant changes, he can rarely become familiar."

-Carl von Clausewitz

This chapter explains the results of the statistical methods applied to the four parameter sets. Each measure of effectiveness is examined and the data explored to determine the significant parameters. The data are presented using ANOVA tables, Yates' Algorithm and Tukey's simultaneous confidence intervals. The data are displayed using Scatter plots, Trellis plots and Design plots. The intent is to provide insight into the ISAAC parameters explored and relate them to the four questions discussed earlier.

A. TIME TO MISSION COMPLETION (MOE 1)

Time critical missions cause the LC to prioritize or alter the decisions being made to incorporate the element of time into the mission. Incorporating the element of time causes changes in the tactics. ISAAC was evaluated, using MOE 1, to determine if the results were reasonable and could be related to combat situations. There were four areas of ISAAC explored using MOE 1. They were patch type and command radius, bond, friction and LC sensor range. The analysis focused on two points. (1) was there a statistical difference in MOE 1 when varying the parameters, and (2) could the results be considered reasonable?

1. Patch Type and Command Radius

The patch type and command radius were varied to explore the effects on MOE 1. These parameters effect the size of the LC's command area, which effects the movement guidance given to the subordinate ISAACAs. The patch type was varied from a one (a 3x3 command area block) to a two (a 5x5 command area block). The command radius was varied from a one (3x3 sub-blocks) to a two (5x5 sub-blocks). Therefore with a patch type of one and a command radius of one there would be:

$$3(2r+1) \times 3(2r+1) = 9 \times 9 \text{ sub-block command area} \tag{8}$$

The only personality parameter varied was the LC propensity to go towards the red goal (w6). Therefore, the effects of Command Area size could be compared with other w6 weights.

In Figure 11 below, each data point is the mean of ten interactive runs with different initial seeds. The x-axis is the number of blue ISAACAs killed and the y-axis is the time for all three squads to reach the red goal. This is the time to mission completion (MOE 1). The similar colors reflect the parameters having the same weight (w6) but different command patch and command radius values. Referring to Figure 11, there is little difference in mission completion time between the command areas with the same LC w6 weight.

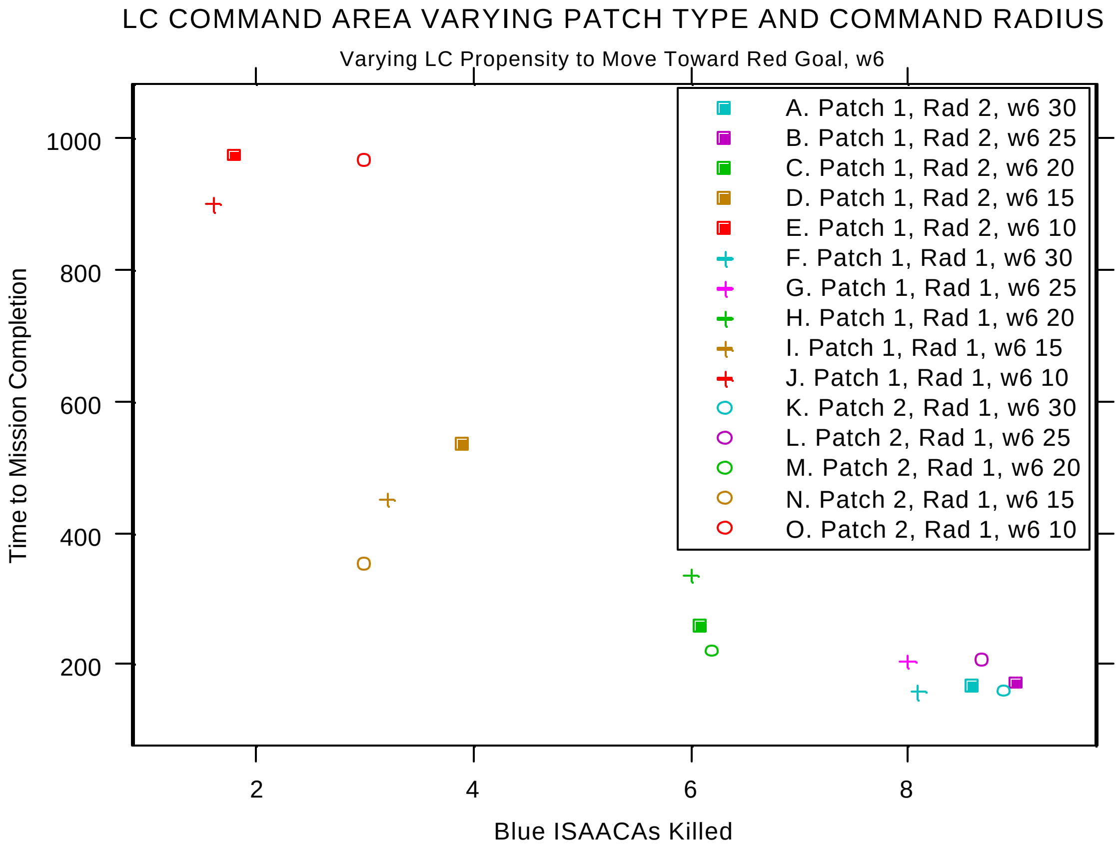


Figure 11: Command Area Size. Varying the Patch Type and Command Radius with different LC personality weight w6 for a comparison of mission completion times. No significant change in mission completion times was noted with different command area sizes.

This can also be seen in Table 1 below using Tukey's method of simultaneous confidence intervals. For each treatment pair mean, Table 1 provides an estimate of the difference, an estimate of the standard error, and the lower and upper bonds for a 90% confidence interval on the differences in means. An asterisk indicates a significant difference. These are statistically significant comparisons and they correspond to pairs of means that can be declared different by Tukey's method.

The difference in mission completion time occurred when the LC personality weight w6 was varied, but not when the command area size was changed. For example, there was no statistical difference in A, F, or K but there was a statistical difference in A and E.

```
response variable: TIME

intervals excluding 0 are flagged by '****'

    Estimate Std.Error Lower Bound Upper Bound
A-B     -4.1       112      -391.0       383.0
A-C    -90.3       112      -478.0       297.0
A-D   -366.0       112      -753.0        21.5
A-E   -805.0       112     -1190.0      -417.0 ****
A-F      9.2       112      -378.0       397.0
A-G    -37.5       112      -425.0       350.0
A-H   -168.0       112      -556.0       219.0
A-I   -283.0       112      -670.0       104.0
A-J   -731.0       112     -1120.0      -344.0 ****
A-K      8.0       112      -379.0       395.0
A-L    -38.9       112      -426.0       348.0
A-M    -52.0       112      -439.0       335.0
A-N   -184.0       112      -572.0       203.0
A-O   -796.0       112     -1180.0      -409.0 ****
B-C    -86.2       112      -474.0       301.0
B-D   -362.0       112      -749.0        25.6
B-E   -801.0       112     -1190.0      -413.0 ****
B-F     13.3       112      -374.0       401.0
B-G    -33.4       112      -421.0       354.0
B-H   -164.0       112      -552.0       223.0
B-I   -279.0       112      -666.0       108.0
B-J   -727.0       112     -1110.0      -340.0 ****
B-K     12.1       112      -375.0       399.0
B-L    -34.8       112      -422.0       353.0
B-M    -47.9       112      -435.0       339.0
B-N   -180.0       112      -567.0       207.0
B-O   -792.0       112     -1180.0      -405.0 ****
C-D   -276.0       112      -663.0       112.0
C-E   -715.0       112     -1100.0      -327.0 ****
C-F     99.5       112      -288.0       487.0
C-G     52.8       112      -335.0       440.0
C-H    -78.0       112      -465.0       309.0
C-I   -193.0       112      -580.0       195.0
C-J   -641.0       112     -1030.0      -253.0 ****
C-K     98.3       112      -289.0       486.0
C-L     51.4       112      -336.0       439.0
```

C-M	38.3	112	-349.0	426.0	
C-N	-93.9	112	-481.0	293.0	
C-O	-706.0	112	-1090.0	-319.0	****
D-E	-439.0	112	-826.0	-51.7	****
D-F	375.0	112	-12.3	762.0	
D-G	328.0	112	-59.0	716.0	
D-H	197.0	112	-190.0	585.0	
D-I	82.8	112	-305.0	470.0	
D-J	-365.0	112	-753.0	22.0	
D-K	374.0	112	-13.5	761.0	
D-L	327.0	112	-60.4	714.0	
D-M	314.0	112	-73.5	701.0	
D-N	182.0	112	-206.0	569.0	
D-O	-430.0	112	-818.0	-43.2	****
E-F	814.0	112	427.0	1200.0	****
E-G	767.0	112	380.0	1150.0	****
E-H	637.0	112	249.0	1020.0	****
E-I	522.0	112	134.0	909.0	****
E-J	73.7	112	-314.0	461.0	
E-K	813.0	112	425.0	1200.0	****
E-L	766.0	112	379.0	1150.0	****
E-M	753.0	112	365.0	1140.0	****
E-N	621.0	112	233.0	1010.0	****
E-O	8.5	112	-379.0	396.0	
F-G	-46.7	112	-434.0	341.0	
F-H	-177.0	112	-565.0	210.0	
F-I	-292.0	112	-680.0	95.1	
F-J	-740.0	112	-1130.0	-353.0	****
F-K	-1.2	112	-389.0	386.0	
F-L	-48.1	112	-435.0	339.0	
F-M	-61.2	112	-449.0	326.0	
F-N	-193.0	112	-581.0	194.0	
F-O	-805.0	112	-1190.0	-418.0	****
G-H	-131.0	112	-518.0	257.0	
G-I	-245.0	112	-633.0	142.0	
G-J	-694.0	112	-1080.0	-306.0	****
G-K	45.5	112	-342.0	433.0	
G-L	-1.4	112	-389.0	386.0	
G-M	-14.5	112	-402.0	373.0	
G-N	-147.0	112	-534.0	241.0	
G-O	-759.0	112	-1150.0	-371.0	****
H-I	-115.0	112	-502.0	273.0	
H-J	-563.0	112	-950.0	-175.0	****
H-K	176.0	112	-211.0	564.0	
H-L	129.0	112	-258.0	517.0	
H-M	116.0	112	-271.0	504.0	
H-N	-15.9	112	-403.0	371.0	
H-O	-628.0	112	-1020.0	-241.0	****
I-J	-448.0	112	-835.0	-60.8	****
I-K	291.0	112	-96.3	678.0	
I-L	244.0	112	-143.0	631.0	
I-M	231.0	112	-156.0	618.0	
I-N	98.8	112	-289.0	486.0	
I-O	-513.0	112	-901.0	-126.0	****
J-K	739.0	112	352.0	1130.0	****
J-L	692.0	112	305.0	1080.0	****
J-M	679.0	112	292.0	1070.0	****
J-N	547.0	112	160.0	934.0	****
J-O	-65.2	112	-453.0	322.0	
K-L	-46.9	112	-434.0	340.0	

K-M	-60.0	112	-447.0	327.0	
K-N	-192.0	112	-580.0	195.0	
K-O	-804.0	112	-1190.0	-417.0	****
L-M	-13.1	112	-400.0	374.0	
L-N	-145.0	112	-533.0	242.0	
L-O	-757.0	112	-1140.0	-370.0	****
M-N	-132.0	112	-520.0	255.0	
M-O	-744.0	112	-1130.0	-357.0	****
N-O	-612.0	112	-999.0	-225.0	****

Table 1. Tukey's 90% simultaneous confidence intervals for command area data. There are no differences among the command areas with the same w6 weighting.

The results did not allow for an adequate evaluation of time to mission completion. ISAAC's inability to reflect any change in time to mission completion for differing command area size, makes it difficult to use this function in mission planning. This will be discussed further in the recommendation section.

2. Bond

The next area examined, using MOE 1, was the bond that exists between the LC and the subordinates. Bond is the weight the individual subordinate ISAACA assigns in the movement penalty function to staying close to the LC. Examining Figure 12 and Table 2, the bond that exists between the LC and the subordinates does not have any significant effect on the time to mission completion. In Figure 12, the bond is varied from high to low (1.0 to 0.1) and there is no significant change in the time to mission completion. The same variations in bond are used in several different LC w6 weights and subordinate ISAACA w6 weights. The results were very similar to those stated above. The influence of bond will be examined further in the following section using number of blue ISAACAs killed (MOE 2).

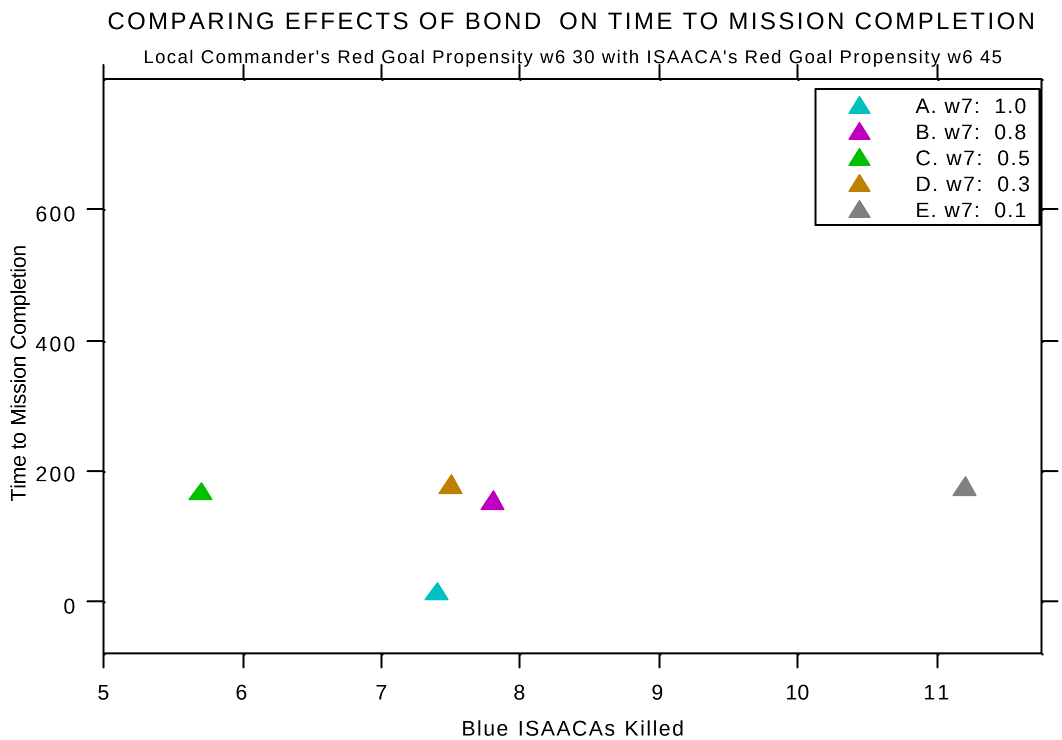


Figure 12: A comparison of bond and its effects on time to mission completion. The bond was varied and the time to mission completion was plotted. No significant effect on mission completion time was noted.

The similar results can also be seen in Table 2 below. Using Tukey's method of simultaneous confidence intervals, there are no confidence intervals that appear to be significant. Similar analysis was done varying the LC and subordinate propensity to move towards the red goal, weight w6. However, in all cases explored the results are similar. In ISAAC, the bond that exists between the LC and his subordinates is not significant in effecting the time to mission completion in any scenario. Bond alone did not influence the battlefield in the urban scenario. In the next section, it will be shown that bond alone had little effect on the battlefield, but the bond:friction interaction significantly influenced the battlefield.

```
90 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method

response variable: TIME

intervals excluding 0 are flagged by '****'

    Estimate Std.Error Lower Bound Upper Bound
A-B     -1.7      18.5       -58.0        54.6
A-C    -15.9      18.5       -72.2        40.4
A-D    -25.8      18.5       -82.1        30.5
A-E    -23.0      18.5       -79.3        33.3
B-C    -14.2      18.5       -70.5        42.1
B-D    -24.1      18.5       -80.4        32.2
B-E    -21.3      18.5       -77.6        35.0
C-D     -9.9      18.5       -66.2        46.4
C-E     -7.1      18.5       -63.4        49.2
D-E      2.8      18.5       -53.5        59.1
D-F     10.4      18.5       -45.9        66.7
```

Table 2. Tukey's 90% simultaneous confidence intervals on the effect of bond on time to mission completion. Varying bond had no significant effect on time to mission completion.

3. Friction

Friction is the ability of a subordinate ISAACA to listen to the LC. The effect of friction on the time to mission completion was also explored. In Figure 13 below, the friction level was varied from low to high (1.0 to 0.1) and the time to mission completion was plotted. In the example in Figure 13, the LC's propensity to move toward the red goal (w6) was low (15) and the subordinate ISAACA's propensity to move toward the red goal (w6) was high (45). There was a significant difference in time to mission completion with the friction level at 0.5 and 0.3. This result also occurred in other situations where the LC's propensity to move toward the red goal was low (w6=15) and the subordinate ISAACA's propensity to move toward the red goal was somewhat higher (w6= 35 or 45). There was no significant difference in time to mission completion when the w6 weightings of both the LC and the subordinate were close. This can also be seen in the Tukey's simultaneous confidence intervals in Table 3 below.

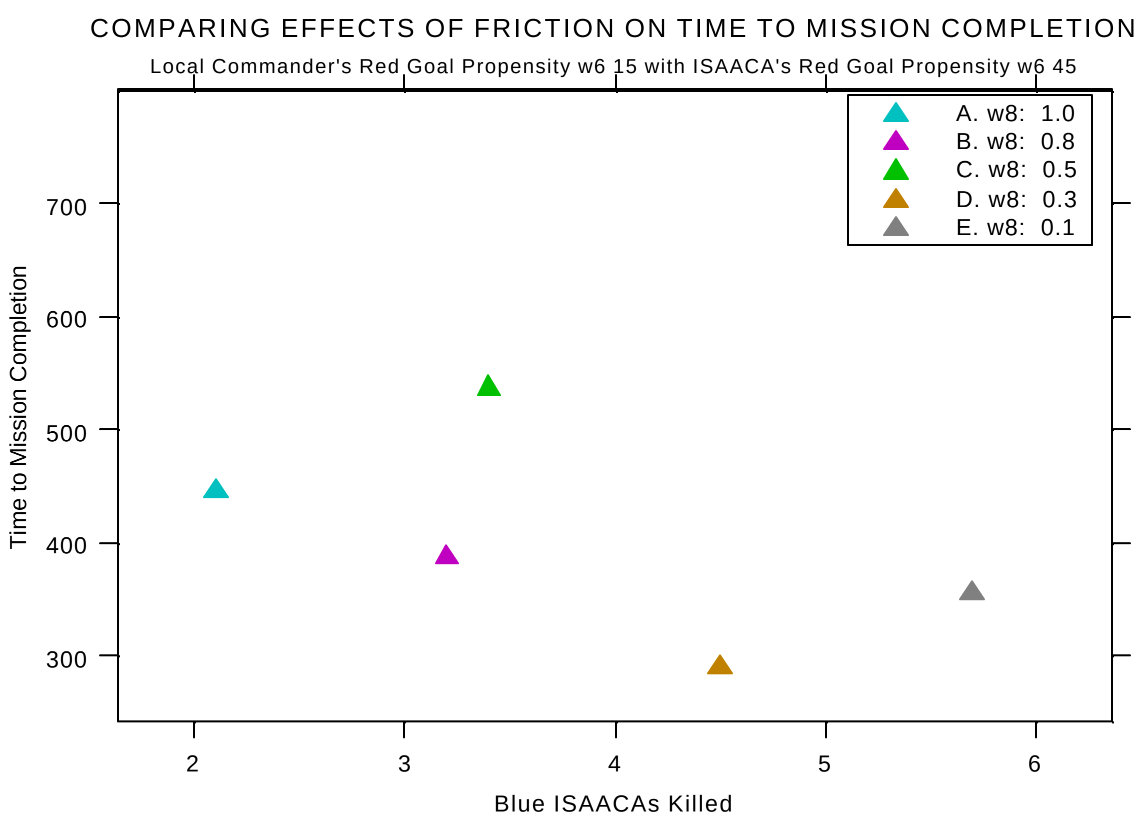


Figure 13: A comparison of friction on time to mission completion.

```
90 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method

response variable: TIME

intervals excluding 0 are flagged by '****'

    Estimate Std.Error Lower Bound Upper Bound
A-B     57.7      91.3      -174.0         289
A-C    -92.0      91.3      -324.0         140
A-D    154.0      91.3       -77.2         386
A-E     90.1      91.3      -142.0         322
B-C   -150.0      91.3      -381.0          82
B-D     96.8      91.3      -135.0         329
B-E     32.4      91.3      -199.0         264
C-D    246.0      91.3        14.8         478 ****
C-E    182.0      91.3       -49.6         414
D-E    -64.4      91.3      -296.0         167
```

Table 3. Tukey's 90% simultaneous confidence intervals on the effect of friction on time to mission completion.

I believe the cases above where friction had a significant impact on the time to mission completion are reasonable. When the subordinate ISAACA's ability to listen is low, implying the friction level to be high, the ISAACA no longer can use the LC's movement guidance. When this occurs, the ISAACA defaults to its own movement propensity towards the red goal. When the subordinates ISAACA's movement propensity is high, the time to mission completion is greatly effected. The subordinate ISAACA departs from the LC mission intent or objective. This departure from the commanders intent violates a fundamental principle in command and control [Ref 10]. The friction level also has significant effects on the number of blue ISAACAs killed, which will be discussed in the following section.

4. Local Commander Sensor Range

The LC's sensor range was the final area where analysis using mission completion time was conducted. The LC's sensor range was varied from 18 to 6. The subordinate ISAACA's sensor range was 8 throughout all the simulation runs. The purpose was to see if an increase in the LC's sensor range caused changes in the tactics or maneuvering done by the LC, which affects the time to mission completion. Increasing the LC's sensor range increases the amount of information available to the commander concerning his immediate area. This information change greatly impacts the LC's movement penalty function and the application of the LC user-specified personality weights. Based on Figure 14, it is apparent that with a high sensor range the mission completion time is high. As the sensor range is decreased, the mission completion time also decreased. This result is consistent in similar simulations where the propensities to move toward the red goal of both LC and subordinate ISAACAs are varied. This can also be seen in the simultaneous confidence intervals in the Table 4 below.

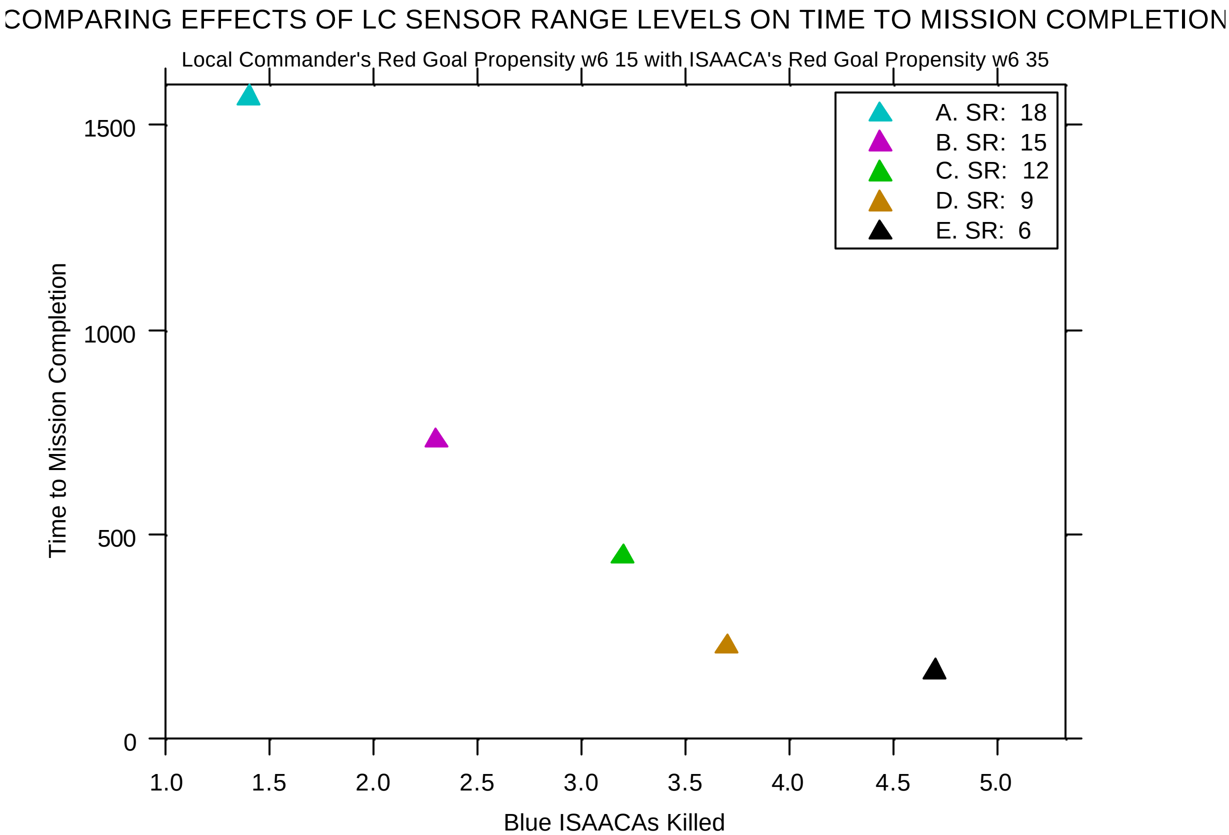


Figure 14: Comparing effects of LC sensor range on time to mission completion. As the LC sensor range is decreased the time to mission completion is decreased.

90 % simultaneous confidence intervals for specified
linear combinations, by the Tukey method

response variable: TIME

intervals excluding 0 are flagged by '****'

	Estimate	Std.Error	Lower Bound	Upper Bound	
A-B	838.0	147	465.0	1210	****
A-C	1120.0	147	749.0	1490	****
A-D	1340.0	147	970.0	1720	****
A-E	1400.0	147	1030.0	1780	****
B-C	284.0	147	-88.6	657	
B-D	505.0	147	132.0	878	****
B-E	566.0	147	193.0	939	****
C-D	221.0	147	-152.0	594	
C-E	282.0	147	-90.9	655	
D-E	61.2	147	-312.0	434	

Table 4. Tukey’s 90% simultaneous confidence intervals. In almost all cases the LC sensor significantly effected time to mission completion.

The results seem very intuitive in this case. Increasing the LC’s information forces the LC to maneuver more to avoid red forces, which takes more time. This is reflected in mission completion time. The relationship between sensor range and mission completion time appears nonlinear. This result directly reflects the decision-makers dilemma when put in a situation with a time critical mission. Although the number of blue ISAACAs killed will be discussed more in the following section, it is obvious from the graph that an increased sensor range reduces kills. However, the high sensor range dramatically increases the time to mission completion. As the sensor range is decreased slightly, the number of kills increases by one but the mission completion time is more than cut in half.

This leads one to wonder if an acceptable rate of advance can be found that still minimizes losses. Receiving reinforcements is not a capability currently in ISAAC.

However, the red forces might receive reinforcements in the real world. The tactics used change as mission priorities change. The LC maneuvers considerably more with greater sensor range. ISAAC allows the decision-maker to explore these tactical options.

ISAAC provided limited insight into completion of mission objectives using MOE 1. This, in part, was due to the statistical limitations of MHPCC. MHPCC did not allow the time to mission completion to be recorded when all three squads reached the goal. MHPCC, in this case, recorded the time the first blue ISAACA reached the red goal. It was difficult to perform the multiple runs necessary to fully explore the effects on mission completion time. Also, without the benefit of multiple runs, it is difficult to gain insight into the sometime complex interactions that can occur when dealing with multiple variables. Despite this difficulty, there were areas that have promise in providing insight into command and control. The LC sensor range and friction levels provided some interesting areas that could be explored in follow-on research. These areas stimulate the user to play and replay scenarios in a "what if" type game, which is the primary purpose of an exploratory tool like ISAAC.

B. BLUE ISAACAS KILLED (MOE 2)

This measure allowed the use of the full computational capabilities of the MHPCC. The four parameter sets are explored using multiple runs, which were conducted to explore the effects of the parameters on the number of blue ISAACAs killed. The results were examined using MOE 2 to determine the significant parameters, and to identify trends. The results proved to be interesting, informative, and provided insight into the capabilities of ISAAC.

1. Command Parameters

The Command Area Parameters include the four personality weights in the command area. The weights are alpha, beta, delta, and gamma. They describe the relative degree of importance the LC places on the friendly and enemy ISAACA information contained in each block of sites within the command area, see Command Parameters section. The parameters are varied from 1.0 to -1.0, in the factorial design discussed previously, and the response is the number of blue ISAACAs killed. Table 5 is the ANOVA table with the results of the multiple runs. It is apparent that in the full factorial design the only significant effect was the alpha parameter. This is the LC's relative degree of importance to the number of alive friendly ISAACAs minus alive enemy ISAACAs when compared to the total number of friendly ISAACAs. The higher order interactions all proved to be insignificant.

ANOVA for Command Parameters in Urban Scenario

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
alpha	4	5.2834	1.320843	6.560354	0.0000356
beta	4	0.8793	0.219828	1.091839	0.3595805
delta	4	0.8059	0.201483	1.000724	0.4064788
gamma	4	1.2332	0.308290	1.531214	0.1914590
alpha:beta	16	2.4527	0.153294	0.761378	0.7301404
alpha:delta	16	3.9670	0.247936	1.231446	0.2380569
beta:delta	16	3.9767	0.248543	1.234463	0.2358099
alpha:gamma	16	3.1038	0.193989	0.963501	0.4956480
beta:gamma	16	1.1670	0.072938	0.362265	0.9897919
delta:gamma	16	1.9484	0.121773	0.604822	0.8813196
alpha:beta:delta	64	12.8016	0.200024	0.993480	0.4939123
alpha:beta:gamma	64	6.2931	0.098329	0.488381	0.9997247
alpha:delta:gamma	64	10.4731	0.163642	0.812775	0.8494638
beta:delta:gamma	64	7.9808	0.124701	0.619362	0.9910275
alpha:beta:delta:gamma	256	33.8161	0.132094	0.656084	0.9999464
Residuals	625	125.8357	0.201337		

Residual standard error: 0.4487061
Estimated effects are balanced

Table 5. ANOVA table for Command Area Parameters. The alpha parameter is the only significant parameter.

Since the higher order interactions are insignificant the ANOVA is conducted again. This time, however, the higher order interactions are considered noise and the F-value and p-value of the main effects and first order interactions are recalculated. Once again, the only significant parameter is alpha.

```
ANOVA with main effects and first order interactions.


               Df Sum of Sq  Mean Sq  F Value     Pr(F)
      alpha    4    5.2834 1.320843 7.615597 0.0000047
       beta    4    0.8793 0.219828 1.267462 0.2808916
      delta    4    0.8059 0.201483 1.161692 0.3261119
      gamma    4    1.2332 0.308290 1.777512 0.1309963
 alpha:beta   16    2.4527 0.153294 0.883847 0.5882359
alpha:delta   16    3.9670 0.247936 1.429526 0.1196204
alpha:gamma   16    3.1038 0.193989 1.118482 0.3318395
 beta:delta   16    3.9767 0.248543 1.433029 0.1180881
 beta:gamma   16    1.1670 0.072938 0.420536 0.9777844
delta:gamma   16    1.9484 0.121773 0.702109 0.7939706
  Residuals 1137  197.2004 0.173439

Residual standard error: 0.4164604
Estimated effects are balanced
```

Table 6. ANOVA with main effects and first order interactions. The higher order interactions are assumed to be noise.

Since the above results are produced with only one replicate run in the factorial design, it is necessary to get a better intuitive feel for these results. With only the main effect significant and no corresponding significant interaction terms, alpha can be examined independently. Figure 15 is a Design plot that reflects the impact of the main effects on the number of blue ISAACAs killed.

Design plots are generated by S-Plus and are diagnostic plots utilized to explore the data. The x-axis is represents the factors present in the data. The y-axis represents the mean of blue ISAACAs killed. The plot reflects the affect each factor has on the number of blue ISAACAs killed. Each factor is displayed with a breakdown of its estimated effects at each level. A weakness in the Design plot is that it does not reflect the affect of interactions between the factors. However, Design plots provide a clear concise initial look at the data. Design plots are also effective if the affect of the interaction terms between factors is small.

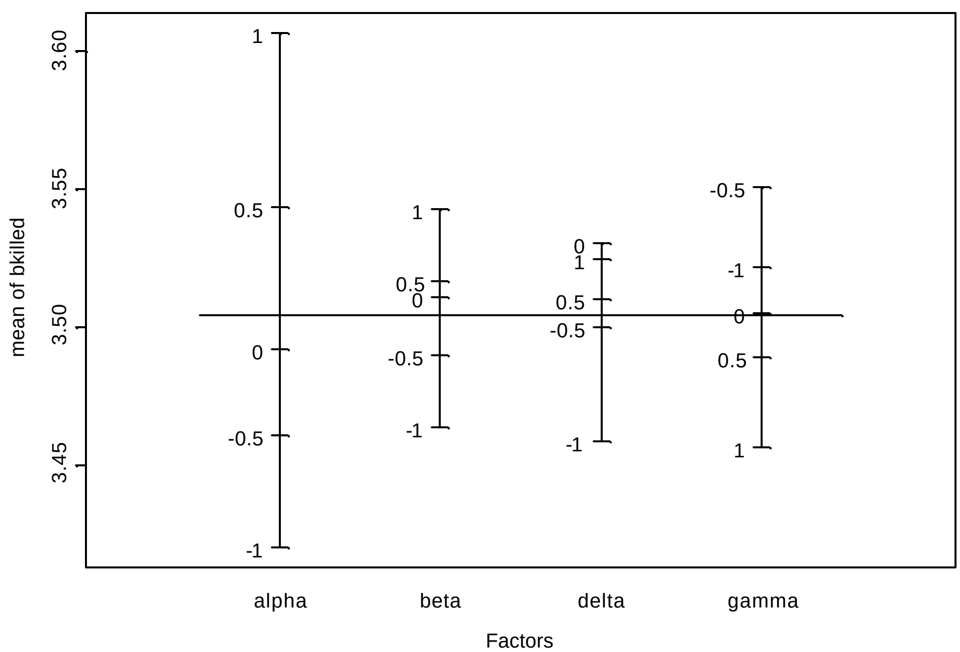


Figure 15: Design plot reflecting the impact of main effects on blue ISAACAs killed. The small mean range of blue ISAACAs killed brings question to the practical significance of alpha.

When considering the effect of alpha, it is important to note that the mean range in blue ISAACAs killed is only 3.43 – 3.61. Alpha has a much greater influence on the results then the other parameters. However, this result is difficult to interpret as practically significant when the mean range of blue killed is only .18.

The Command Area Parameters in the desert scenario, LCAMY.MHP, are also examined. The ANOVA table is Table 7 below. There are no significant parameters in the ANOVA. With no significant parameters and a Design plot that reflects a similar small range of blue ISAACAs killed (4.39 – 4.55), it is difficult to come to any conclusion in the desert scenario other than the command area parameters don't affect the response.

```
ANOVA using Desert scenario
                       Df Sum of Sq   Mean Sq  F Value     Pr(F)
                 alpha  2   0.42936 0.2146802 0.962837 0.3861341
                  beta  2   0.88839 0.4441955 1.992210 0.1430214
                 delta  2   0.61297 0.3064830 1.374571 0.2587845
                 gamma  2   0.13084 0.0654177 0.293397 0.7465148
            alpha:beta  4   1.56073 0.3901818 1.749959 0.1470946
           alpha:delta  4   0.63288 0.1582203 0.709616 0.5876980
            beta:delta  4   0.48917 0.1222933 0.548484 0.7006314
           alpha:gamma  4   0.67260 0.1681506 0.754153 0.5581556
            beta:gamma  4   0.51596 0.1289911 0.578523 0.6790246
           delta:gamma  4   0.40690 0.1017253 0.456237 0.7675767
      alpha:beta:delta  8   1.88432 0.2355402 1.056394 0.4018191
      alpha:beta:gamma  8   1.39774 0.1747170 0.783603 0.6183455
     alpha:delta:gamma  8   1.38276 0.1728451 0.775208 0.6255694
      beta:delta:gamma  8   0.69859 0.0873233 0.391644 0.9221185
alpha:beta:delta:gamma 16   4.45070 0.2781689 1.247583 0.2518848
             Residuals 81  18.06026 0.2229662

Residual standard error: 0.472193
Estimated effects are balanced
```

Table 7. ANOVA from Desert scenario.

The significance of alpha in the urban scenario could imply that command parameters are scenario dependent. Once again, this does not aid in finding a relevant interpretation of alpha, or the other three command area parameters. Also, the small variance in the number of blue ISAACAs killed, in both scenarios, does not provide any insight into the command parameters. It is difficult to gain an intuitive feel for these parameters. The small change in the blue ISAACAs killed leads one to the assumption that these parameters do not significantly effect the results in the urban scenario or the desert scenario. Knowing that parameters tend not to affect results means future researchers can pay less attention to them when assessing the effects of other parameters. This issue will be further addressed in the recommendation section.

2. Local Commander Personality Weights

There were five LC personality weights varied in this parameter set. They were the LC's propensity to move toward aliveB, aliveR, injrdB, injrdR, and Rgoal. The data were run with one replicate (average of 100 runs for each factor combination), and then a square root power transformation was performed on the response. Table 8 is the ANOVA table for the LC Personality Weights.

The ANOVA table lists the five factors and the interaction terms that occur between the five factors. The ANOVA table displays the sum of squares, mean sum of squares, F-value, and p-value as described in the methodology section. The p-value indicates whether a factor or interaction term is significant. In Table 8 and subsequent ANOVA tables, the degrees of freedom (df) can be misleading. For the main factors, the dfs are two. However, each data point is the average of 100 runs for that combination of factors.

ANOVA table for LC Personality Weights

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
aliveB	2	214.9169	107.4584	18706.52	0.0000000
aliveR	2	177.6512	88.8256	15462.89	0.0000000
injrdB	2	2.9229	1.4615	254.41	0.0000000
injrdR	2	0.9368	0.4684	81.54	0.0000000
Rgoal	2	24.1829	12.0914	2104.90	0.0000000
aliveB:aliveR	4	11.4855	2.8714	499.85	0.0000000
aliveB:injrdB	4	1.1687	0.2922	50.86	0.0000000
aliveR:injrdB	4	0.2008	0.0502	8.74	0.0000013
aliveB:injrdR	4	0.2690	0.0672	11.71	0.0000000
aliveR:injrdR	4	0.3906	0.0976	17.00	0.0000000
injrdB:injrdR	4	0.0420	0.0105	1.83	0.1240452
aliveB:Rgoal	4	3.7726	0.9431	164.18	0.0000000
aliveR:Rgoal	4	24.9459	6.2365	1085.65	0.0000000
injrdB:Rgoal	4	0.0242	0.0060	1.05	0.3808284
injrdR:Rgoal	4	0.6690	0.1672	29.12	0.0000000
aliveB:aliveR:injrdB	8	0.1436	0.0180	3.12	0.0022175
aliveB:aliveR:injrdR	8	0.3404	0.0425	7.41	0.0000000
aliveB:injrdB:injrdR	8	0.0280	0.0035	0.61	0.7694956
aliveR:injrdB:injrdR	8	0.0580	0.0072	1.26	0.2643771
aliveB:aliveR:Rgoal	8	5.9202	0.7400	128.83	0.0000000
aliveB:injrdB:Rgoal	8	0.3302	0.0413	7.19	0.0000000
aliveR:injrdB:Rgoal	8	0.1552	0.0194	3.38	0.0010793
aliveB:injrdR:Rgoal	8	0.0853	0.0107	1.86	0.0674759
aliveR:injrdR:Rgoal	8	0.8710	0.1089	18.95	0.0000000
injrdB:injrdR:Rgoal	8	0.0092	0.0011	0.20	0.9907232
aliveB:aliveR:injrdB:injrdR	16	0.1106	0.0069	1.20	0.2657148
aliveB:aliveR:injrdB:Rgoal	16	0.1538	0.0096	1.67	0.0524339
aliveB:aliveR:injrdR:Rgoal	16	0.3538	0.0221	3.85	0.0000021
aliveB:injrdB:injrdR:Rgoal	16	0.1541	0.0096	1.68	0.0517436
aliveR:injrdB:injrdR:Rgoal	16	0.0887	0.0055	0.97	0.4954186
aliveB:aliveR:injrdB:injrdR:Rgoal	32	0.1054	0.0033	0.57	0.9695300
Residuals	243	1.3959	0.0057		

Table 8. ANOVA table for LC Personality Weights.

Based on the ANOVA above, all main effects and many of the higher order interactions are significant. For the main effects, aliveB and aliveR have by far the largest sum of squares. The LC movement propensity in regards to alive blues and alive reds accounts for approximately 80% of the total sum of squares. The other effects that stand out are Rgoal, aliveB:aliveR interaction, and aliveR:Rgoal interaction. These LC movement propensities also have an influence on the battlefield.

The sum squares for the higher order interactions are very small with many degrees of freedom (dfs). This suggests that there may only be a small number of the dfs in the interaction terms that are actually significant. If this hypothesis is true, then combined with the small sum of squares when compared to the main effects, it is a reasonable assumption to consider the higher order interactions as insignificant or noise. In order to justify this assumption, Yates' Algorithm is used.

a. Yates' Algorithm

Yates' Algorithm provides a means of breaking down the dfs in the higher order interactions into their linear and quadratic effects. Table 9 is an ANOVA table using Yates' Algorithm with the higher order interaction dfs separated into four df groupings.

Transformed LC Personality Weights

a=aliveB b=aliveR c=injrdB d=injrdR E=Rgoal
L=Linear Term Q=Quadratic Term

ANOVA	SS	df	mean square	Fo	Pr(F)
a=aL+aQ	**214.91689**	**2**	**107.45844**	**18852.358**	3.02E-267
aL	190.90728	1	190.90728	33492.505	2.51E-262
aQ	24.009609	1	24.009609	4212.2121	1.72E-155
b=bL+bQ	**177.65119**	**2**	**88.825596**	**15583.438**	2.87E-257
bL	177.0484	1	177.0484	31061.123	2.22E-258
bQ	0.6027908	1	0.6027908	105.75278	7.927E-21
c=cL+cQ	**2.9229235**	**2**	**1.4614617**	**256.3968**	1.334E-60
cL	2.9216697	1	2.9216697	512.57363	8.563E-62
cQ	0.0012538	1	0.0012538	0.2199624	0.639489
d=dL+dQ	**0.9368164**	**2**	**0.4684082**	**82.176873**	5.49E-28
dL	0.8379825	1	0.8379825	147.01447	8.964E-27
dQ	0.0988339	1	0.0988339	17.339273	4.345E-05
e=eL+eQ	**24.182897**	**2**	**12.091448**	**2121.3067**	1.43E-154

eL	24.078658	1	24.078658	4224.326	1.23E-155
eQ	0.1042388	1	0.1042388	18.287512	2.732E-05
ab	**11.485496**	**4**	**2.871374**	**503.74982**	2.59E-116
axbL=abLxL+abQxL	0.0629873	2	0.0314937	5.5252028	0.0045019
axbQ=abLxQ +abQxQ	11.422509	2	5.7112543	1001.9744	4.29E-118
ac	**1.1687403**	**4**	**0.2921851**	**51.260538**	2.943E-31
axcL=acLxL+acQxL	1.1586773	2	0.5793386	101.63836	8.399E-33
axcQ=acLxQ +acQxQ	0.010063	2	0.0050315	0.8827197	0.4149785
ad	**0.2689615**	**4**	**0.0672404**	**11.796556**	8.976E-09
axdL=adLxL+adQxL	0.2373959	2	0.118698	20.824202	4.494E-09
axdQ=adLxQ +adQxQ	0.0315656	2	0.0157828	2.7689105	0.0647106
ae	**3.772555**	**4**	**0.9431388**	**165.46294**	3.807E-68
axeL=aeLxL+aeQxL	2.6664736	2	1.3332368	233.90119	2.31E-57
axeQ=aeLxQ + aeQxQ	1.1060815	2	0.5530407	97.024692	1.063E-31
bc	**0.200765**	**4**	**0.0501913**	**8.8054841**	1.18E-06
bxcL=bcLxL+bcQxL	0.1889223	2	0.0944612	16.572133	1.791E-07
bxcQ=bcLxQ + bcQxQ	0.0118427	2	0.0059214	1.0388348	0.3554329
bd	**0.3905604**	**4**	**0.0976401**	**17.12984**	2.166E-12
bxdL=bdLxL+bdQxL	0.2192351	2	0.1096176	19.231153	1.764E-08
bxdQ=bdLxQ + bdQxQ	0.1713252	2	0.0856626	15.028527	7.021E-07
be	**24.945855**	**4**	**6.2364637**	**1094.1164**	4.66E-154
bxeL=beLxL+beQxL	23.089753	2	11.544877	2025.4169	2.89E-152
bxeQ="beLxQ" + "beQxQ"	1.8561016	2	0.9280508	162.81593	1.378E-45
cd	**0.0420031**	**4**	**0.0105008**	**1.8422428**	0.1213727
cxdL=cdLxL+cdQxL	1.249E-05	2	6.247E-06	0.001096	0.9989046
cxdQ=cdLxQ+cdQxQ	0.0419906	2	0.0209953	3.6833896	0.0265517
ce	**0.0241812**	**4**	**0.0060453**	**1.0605804**	0.3766713
cxeL=ceLxL+ceQxL	0.0207076	2	0.0103538	1.8164519	0.1648025
cxeQ=ceLxQ + ceQxQ	0.0034737	2	0.0017368	0.3047089	0.7376193
de	**0.6689978**	**4**	**0.1672494**	**29.342008**	6.527E-20
dxeL=deLxL+deQxL	0.635564	2	0.317782	55.751226	1.181E-20
dxeQ=deLxQ +deQxQ	0.0334338	2	0.0167169	2.9327909	0.0551359
abc	**0.1436045**	**8**	**0.0179506**	**3.149222**	0.0020694
abcLxLxL+abcQxLxL	0.0163181	2	0.0081591	1.4314162	0.2409779
abcLxQxL+abcQxQxL	0.1152438	2	0.0576219	10.109101	6.064E-05
abcLxLxQ+abcQxLxQ	0.0094693	2	0.0047346	0.8306379	0.4370047
abcLxQxQ+abcQxQxQ	0.0025734	2	0.0012867	0.2257331	0.7980982
abd	**0.3403876**	**8**	**0.0425485**	**7.4646406**	6.778E-09
abdLxLxL+abdQxLxL	0.2991629	2	0.1495814	26.242355	4.799E-11
abdLxQxL+abdQxQxL	0.003111	2	0.0015555	0.2728978	0.7614036
abdLxLxQ+abdQxLxQ	0.0092481	2	0.0046241	0.8112388	0.4455069
abdLxQxQ+abdQxQxQ	0.0288656	2	0.0144328	2.5320705	0.0815901
abe	**5.9202286**	**8**	**0.7400286**	**129.82958**	3.042E-83
abeLxLxL+abeQxLxL	0.8207944	2	0.4103972	71.999505	2.782E-25

abeLxQxL+abeQxQxL	4.3555729	2	2.1777865	382.0678	9.462E-76
abeLxLxQ+abeQxLxQ	0.0027088	2	0.0013544	0.2376112	0.7886922
abeLxQxQ+abeQxQxQ	0.7411526	2	0.3705763	65.013385	2.425E-23
acd	**0.0280145**	**8**	**0.0035018**	**0.6143531**	0.765503
acdLxLxL+acdQxLxL	0.0071686	2	0.0035843	0.6288267	0.5340825
acdLxQxL+acdQxQxL	0.0130435	2	0.0065218	1.1441703	0.3201977
acdLxLxQ+acdQxLxQ	0.0043745	2	0.0021873	0.3837321	0.681726
acdLxQxQ+acdQxQxQ	0.0034278	2	0.0017139	0.3006833	0.7405872
ace	**0.330204**	**8**	**0.0412755**	**7.2413166**	1.297E-08
aceLxLxL+aceQxLxL	0.3201958	2	0.1600979	28.087353	1.062E-11
aceLxQxL+aceQxQxL	0.0034861	2	0.001743	0.3057967	0.7368193
aceLxLxQ+aceQxLxQ	0.0059599	2	0.00298	0.5228011	0.5935229
aceLxQxQ+aceQxQxQ	0.0005622	2	0.0002811	0.0493154	0.9518904
ade	**0.0853435**	**8**	**0.0106679**	**1.8715689**	0.0650937
adeLxLxL+adeQxLxL	0.007881	2	0.0039405	0.6913199	0.5018969
adeLxQxL+adeQxQxL	0.0467057	2	0.0233528	4.0969903	0.0177845
adeLxLxQ+adeQxLxQ	0.0223709	2	0.0111854	1.9623579	0.1427473
adeLxQxQ+adeQxQxQ	0.0083859	2	0.004193	0.7356076	0.4802782
bcd	**0.0579725**	**8**	**0.0072466**	**1.2713272**	0.2590622
bcdLxLxL+bcdQxLxL	0.0350339	2	0.017517	3.0731522	0.048078
bcdLxQxL+bcdQxQxL	0.0150201	2	0.00751	1.3175495	0.2696968
bcdLxLxQ+bcdQxLxQ	0.0023812	2	0.0011906	0.2088749	0.8116423
bcdLxQxQ+bcdQxQxQ	0.0055373	2	0.0027687	0.4857319	0.6158428
bce	**0.1552012**	**8**	**0.0194002**	**3.4035352**	0.0010007
bceLxLxL+bceQxLxL	0.1219907	2	0.0609954	10.700941	3.516E-05
bceLxQxL+bceQxQxL	0.0091076	2	0.0045538	0.7989097	0.450997
bceLxLxQ+bceQxLxQ	0.0230791	2	0.0115396	2.0244861	0.1342831
bceLxQxQ+bceQxQxQ	0.0010238	2	0.0005119	0.0898034	0.9141412
bde	**0.8710079**	**8**	**0.108876**	**19.101051**	3.393E-22
bdeLxLxL+bdeQxLxL	0.6733549	2	0.3366775	59.06622	1.244E-21
bdeLxQxL+bdeQxQxL	0.017773	2	0.0088865	1.5590361	0.2124352
bdeLxLxQ+bdeQxLxQ	0.1661886	2	0.0830943	14.577948	1.049E-06
bdeLxQxQ+bdeQxQxQ	0.0136914	2	0.0068457	1.2010017	0.3026723
cde	**0.0091673**	**8**	**0.0011459**	**0.2010375**	0.9904779
cdeLxLxL+cdeQxLxL	0.0007277	2	0.0003639	0.0638351	0.9381755
cdeLxQxL+cdeQxQxL	0.0013504	2	0.0006752	0.118452	0.8883457
cdeLxLxQ+cdeQxLxQ	0.0016909	2	0.0008455	0.1483274	0.8622268
cdeLxQxQ+cdeQxQxQ	0.0053983	2	0.0026992	0.4735355	0.62337
abcd	**0.1106073**	**16**	**0.006913**	**1.2127996**	0.2584258
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.0388047	4	0.0097012	1.7019608	0.1501823
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.0230107	4	0.0057527	1.0092401	0.4032771
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.0239657	4	0.0059914	1.0511291	0.3814633
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.0248262	4	0.0062065	1.0888684	0.3626121
abce	**0.1537693**	**16**	**0.0096106**	**1.6860673**	0.0498454

LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.1079404	4	0.0269851	4.7342296	0.0010734
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.002697	4	0.0006743	0.1182904	0.9759221
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.0308487	4	0.0077122	1.3530128	0.2509736
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.0122832	4	0.0030708	0.5387363	0.7074132
abde	**0.3538002**	**16**	**0.0221125**	**3.8793886**	1.773E-06
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.1488045	4	0.0372011	6.5265118	5.275E-05
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.0672711	4	0.0168178	2.9504882	0.0208395
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.1360202	4	0.0340051	5.9658001	0.0001353
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.0017044	4	0.0004261	0.0747544	0.9898102
acde	**0.1540837**	**16**	**0.0096302**	**1.689514**	0.0491809
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.047993	4	0.0119982	2.1049544	0.0808235
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.0300523	4	0.0075131	1.3180828	0.263801
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.0389823	4	0.0097456	1.7097511	0.1484292
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.0370561	4	0.009264	1.6252676	0.168487
bcde	**0.0887311**	**16**	**0.0055457**	**0.9729292**	0.4870498
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.0299683	4	0.0074921	1.3143971	0.2651871
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.0124363	4	0.0031091	0.5454497	0.7025137
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.0152088	4	0.0038022	0.6670517	0.6154316
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.0301191	4	0.0075298	1.3210129	0.2627035
abcde	**0.1054229**	**32**	**0.0032945**	**0.5779762**	0.9677478
			Total Sum of Squares		473.88228

Table 9. Yates' Algorithm of LC Personality Weights. In the higher order interactions there are very few significant degrees of freedom. This combined with the very small sum squares for the higher order interactions allows for the reasonable assumption that the higher order interactions can be interpreted as noise.

Yates' Algorithm supports the hypothesis that the higher order interactions have little significance when compared to all the effects. Therefore, the assumption is justified to consider the higher order interactions as noise. Table 9 also indicates that the linear effects were much more significant then the quadratic effects in most cases. This indicates that this data set is more linear than nonlinear in its behavior. With the higher order interactions taken as noise, the model is significantly simplified. Based on this, Table 10 provides a much clearer picture concerning which LC parameters are significant. Based on the p-value and the sum squares, it is clear that the main effects of aliveB, aliveR and Rgoal are most significant. Also, the first order interactions aliveB:aliveR and aliveR:Rgoal are significant. The main effects and two term interaction effects account for 97% of the total sum of squares.

ANOVA table for LC Personality Weights.
Main Effects and First order Interactions.

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
aliveB	2	214.9169	107.4584	4536.776	0.0000000
aliveR	2	177.6512	88.8256	3750.118	0.0000000
injrdB	2	2.9229	1.4615	61.701	0.0000000
injrdR	2	0.9368	0.4684	19.776	0.0000000
Rgoal	2	24.1829	12.0914	510.488	0.0000000
aliveB:aliveR	4	11.4855	2.8714	121.226	0.0000000
aliveB:injrdB	4	1.1687	0.2922	12.336	0.0000000
aliveB:injrdR	4	0.2690	0.0672	2.839	0.0240434
aliveB:Rgoal	4	3.7726	0.9431	39.818	0.0000000
aliveR:injrdB	4	0.2008	0.0502	2.119	0.0775436
aliveR:injrdR	4	0.3906	0.0976	4.122	0.0027362
aliveR:Rgoal	4	24.9459	6.2365	263.297	0.0000000
injrdB:injrdR	4	0.0420	0.0105	0.443	0.7772752
injrdB:Rgoal	4	0.0242	0.0060	0.255	0.9064343
injrdR:Rgoal	4	0.6690	0.1672	7.061	0.0000163
Residuals	435	10.3034	0.0237		

Table 10. ANOVA table for Command Personality Weights. The main effects and first order interactions are displayed.

b. Fractional Design

The fractional design, discussed earlier, is analyzed to determine if the same results could be determined from a one-third fractional design. Table 11 is the ANOVA table of the 1/3 fractional factorial design. The fractional design requires only 81 factor combinations vice the 243 required in the full factorial design.

ANOVA 1/3 Fractional Design Of LC Personality Weights.

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
aliveB	2	72.43916	36.21958	1236.890	0.0000000
aliveR	2	59.46902	29.73451	1015.427	0.0000000
injrdB	2	1.25195	0.62597	21.377	0.0000000
injrdR	2	0.36909	0.18454	6.302	0.0025561
Rgoal	2	8.21572	4.10786	140.282	0.0000000
aliveB:aliveR	4	3.89678	0.97420	33.269	0.0000000
aliveB:injrdB	4	0.44046	0.11012	3.760	0.0065923
aliveB:injrdR	4	0.09826	0.02457	0.839	0.5033393
aliveB:Rgoal	4	1.23907	0.30977	10.578	0.0000003
aliveR:injrdB	4	0.18975	0.04744	1.620	0.1742188
aliveR:injrdR	4	0.12586	0.03146	1.074	0.3726572
aliveR:Rgoal	4	8.84899	2.21225	75.548	0.0000000
injrdB:injrdR	4	0.11036	0.02759	0.942	0.4424284
injrdB:Rgoal	4	0.06822	0.01705	0.582	0.6760085
injrdR:Rgoal	4	0.33552	0.08388	2.864	0.0265504
Residuals	111	3.25039	0.02928		

Table 11. ANOVA table for the 1/3 fractional factorial design of the LC Personality Weights.

It is readily apparent that, although there are some minor differences in the p-values, the same significant effects appear in the fractional design. Looking at the p-value and the sum squares, the significant main effects are aliveB, alive R, and Rgoal. The significant first order interaction terms are aliveB:aliveR and aliveR:Rgoal. These significant effects account for a similarly large percentage of the total sum of squares; as in the full factorial design. The 1/3 fractional design greatly reduced the overall number of simulation runs.

c. Desert Scenario Data

The same approach is used in analyzing the desert scenario. The full factorial ANOVA, Yates' algorithm, and finally a main effect and first order interaction ANOVA was completed. The analysis of the data lead to identical basic conclusions as the urban scenario data. Table 12 is the ANOVA table of the desert scenario.

ANOVA Desert Scenario.
Main Effects and First Order Interactions.

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
aliveB	2	246.4881	123.2441	2603.910	0.0000000
aliveR	2	279.2307	139.6153	2949.803	0.0000000
injrdB	2	4.3365	2.1682	45.811	0.0000000
injrdR	2	0.1949	0.0975	2.059	0.1287943
Rgoal	2	74.7786	37.3893	789.964	0.0000000
aliveB:aliveR	4	14.9838	3.7459	79.145	0.0000000
aliveB:injrdB	4	1.5337	0.3834	8.101	0.0000026
aliveB:injrdR	4	0.3280	0.0820	1.732	0.1417942
aliveB:Rgoal	4	5.9804	1.4951	31.589	0.0000000
aliveR:injrdB	4	0.7399	0.1850	3.908	0.0039520
aliveR:injrdR	4	0.6417	0.1604	3.390	0.0095528
aliveR:Rgoal	4	49.1231	12.2808	259.469	0.0000000
injrdB:injrdR	4	0.0586	0.0146	0.309	0.8717365
injrdB:Rgoal	4	0.0474	0.0119	0.250	0.9093918
injrdR:Rgoal	4	2.7018	0.6755	14.271	0.0000000
Residuals	435	20.5887	0.0473		

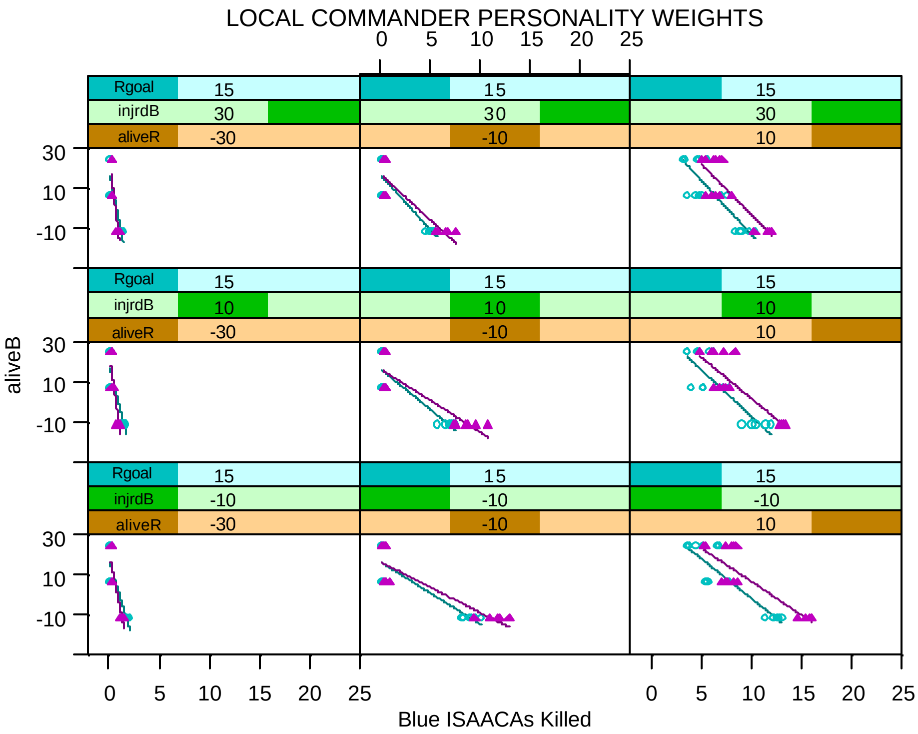
Table 12. ANOVA table of the desert scenario. The main effects and first order interactions are displayed.

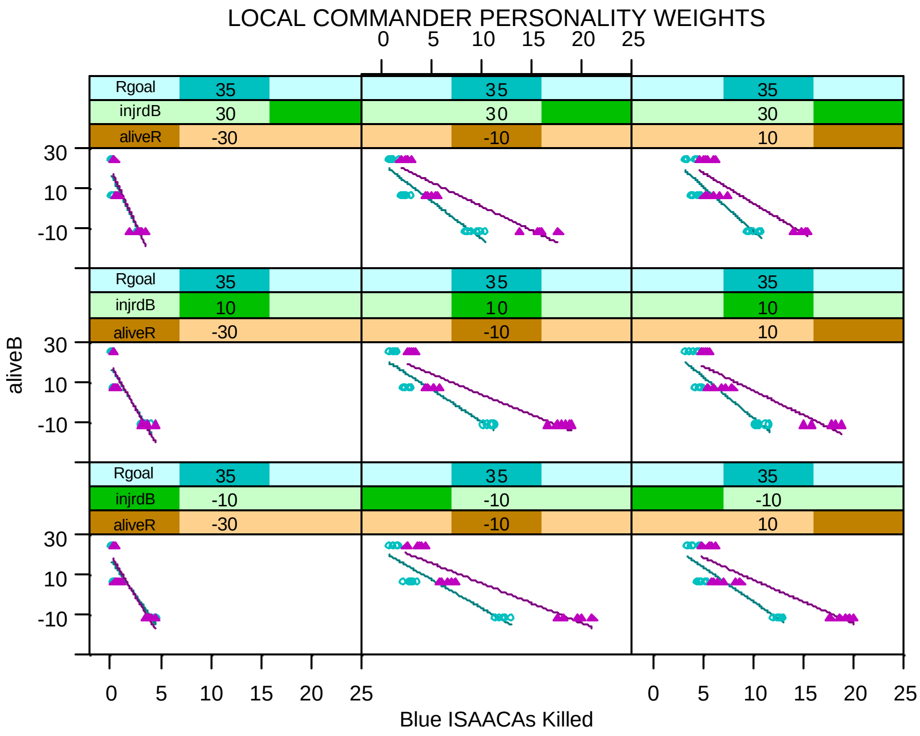
It is clear from the Table 12 that the same main effects and first order interactions, aliveB, aliveR, Rgoal, aliveB:aliveR, and aliveR:Rgoal, constitute a large percentage of the total sum of squares. This finding could indicate that the parameters have some global importance in ISAAC, and are not necessarily scenario dependent. This finding assists in the understanding of ISAAC and the effect of some of the personality weights. The next section aids in an intuitive understanding to these significant parameters.

d. Local Commander Personality Significant Parameters

Three significant data sets were chosen to display with Trellis plots. The response, blue ISAACAs killed, were displayed on the x-axis and a chosen parameter was displayed on the y-axis. The data was conditioned on the three remaining parameters. In each of the three data sets displayed, the least significant parameter is removed. This reduced the number of viewing panels from 81 to 9. This process served two purposes. First, it served to simply the plots to three frames vice twenty-seven for easier readability. Second, it served to remove the parameter that did not have a bearing on the results, which clarified the more significant effects. This type of display allows for clearer representation of these significant main effects and interactions. The desert scenario test data set is then overlaid on the Trellis plots as a comparison. Figures 16, 17, and 18 are Trellis plots that display the urban scenario data in blue circles and the desert scenario data in pink triangles.

In Figure 16, in each panel, the x-axis is the number of blue ISAACAs killed and the y-axis is the most significant first parameter, aliveB. In Figure 16, the parameter that had the least significance in having an impact was removed, injrdR, and the blue ISAACAs killed are conditioned on three parameters. The columns condition on aliveR, the rows condition on injrdB, and the frames condition on Rgoal.


LOCAL COMMANDER PERSONALITY WEIGHTS
Rgoal
injrdB
aliveR
aliveB
Blue ISAACAs Killed


LOCAL COMMANDER PERSONALITY WEIGHTS
Rgoal
injrdB
aliveR
aliveB
Blue ISAACAs Killed

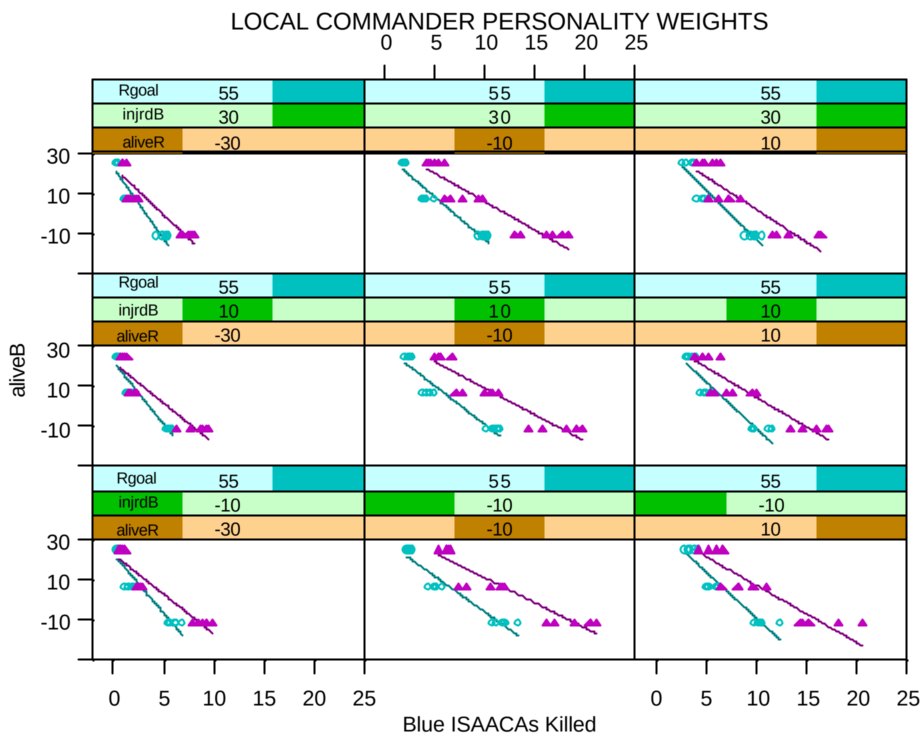


Figure 16: Trellis plot for the LC Personality Weights. The blue circles are the urban scenario data and the pink triangles are the desert scenario data. The columns condition on aliveR, rows condition on injrdB and frames condition on Rgoal.

After examining the Trellis plots, the first noticeable result is that the urban scenario and the desert scenario have very similar data patterns. The urban scenario and the desert scenario data are similar in slope and spread. This similarity is indicated by the best fit line drawn in each of the data frames above. This best fit line allows the user to quickly assess any change in the data from frame to frame. This similarity corresponds to the significant parameters identified in the ANOVA tables. The only difference between the desert scenario and the urban scenario is that there is no terrain in the desert scenario. It appears the desert data has more kills then the urban scenario, on average, but the general relationships between the response and factors hold true.

I believe the reason for the higher average of blue ISAACAs killed is the effect of the terrain. The terrain in the urban scenario has two main effects on the number of Blue ISAACAs killed. First, the terrain provides a barrier to the firing range of the red ISAACAs. It essentially reduces the red firing capability. Second, the terrain in the urban scenario forces more maneuvering by the blue ISAACAs. In this type of urban scenario, the increased maneuvering has the same general result as in similar combat environments by reducing the number of kills.

A few other standout effects are seen in the effects of the parameters aliveB, aliveR, and Rgoal. It is apparent that when the alive blue ISAACA's propensity to attract toward other alive blue ISAACAs is at the medium or high level, the number of kills is reduced. The left to right decreasing slopes of the data indicates the reduced kills. When the aliveB parameter is negative, propensity to repel from other alive blue ISAACAs, the number of blue ISAACAs killed increases dramatically. This result indicates that there is a need for the LC to remain close to the squad or unit. As in many combat situations, unit cohesion increases fire power concentration effects, which increases ability to repel the enemy.

The aliveR parameter (propensity to attract toward other alive red) also had significant results that corresponded to the ANOVA table in Table 12. When the aliveR parameter is at its lowest negative value, the LC had a strong propensity to repel from the other alive red ISAACAs. This movement dramatically reduced the number of blue ISAACAs killed. As the aliveR parameter moved toward higher levels, the number of blue ISAACAs killed increased. This result can be related to a LC needing a strong propensity to move away from or avoid the enemy, thereby reducing losses to his subordinate ISAACAs.

The Rgoal (propensity to move toward the red goal) parameter also influenced the number of blue ISAACAs killed. This effect is apparent in the Trellis plots as number of blue ISAACAs killed increases as the Rgoal level increases. The effect is not as strong as aliveB and alive R effects, and this corresponds to the ANOVA table results in Table 12. However, when the propensity to move toward the red goal is increased, the number of blue ISAACAs killed also increased.

Interestingly, if the increased need to reach the objective is combined with maneuvering or avoiding red ISAACAs, the losses can be limited. The interaction terms verify this finding. The significant interaction terms aliveB:aliveR and aliveR:Rgoal are also readily displayed. If the aliveB parameter is at the middle or high level and the aliveR parameter is kept at the low level, the number of blue ISAACA losses are minimized. Changing aliveR to the middle or high level while increasing the Rgoal propensity to the middle or high level, definitely increases the number of blue ISAACAs killed. This finding supports the fundamental purpose of ISAAC, to allow the user to explore the many possibilities of tactics.

The other main effects and interactions have impact as well. Generally, the effects are not as overwhelming, particularly the injured state effects. In ISAAC, when an ISAACA transitions from the alive to injured state, its sensor and movement capability are reduced. In the injured state, the ISAACA's impact is reduced somewhat. The effects produced by the injured ISAACAs are more subtle and difficult to discern in such an exploratory approach. This finding is confirmed in the ANOVA table where the sum of squares of the injured terms and interactions are very small when compared to the other effects.

For the LC to minimize losses, the aliveB level should be high while the aliveR level and Rgoal level parameters are low. These levels correspond to unit cohesion while maneuvering and maneuvering to avoid the enemy as much as possible. The high aliveB value also allows for concentration of fire when red forces are encountered. Although the LC continues to drive toward the objective, the drive does not become the overriding deciding force. The results seem reasonable and reflect a similar guidance directed by the Marine Corps in the training of its commanders [Ref 11].

3. Blue Subordinate ISAACA Personality Weights

The previous section analyzed the results of varying the LC personality weights. This section will examine the same five parameters as they relate to the subordinate ISAACA personalities. The weights are aliveB, aliveR, injrdB, injrdR, and Rgoal. The data was also run with one replicate and did not require any power transformation to apply the normality assumptions necessary for the analysis.

Table 13 is the ANOVA for the Blue ISAACA Parameter data set. In examining the main effects and high order interactions using the p-values, the four term and five term interactions are not significant at a significance level of .05 or .1. These high order interactions can be assumed as noise. However, in examining the p-values of the three term interactions, the situation is similar to the previous one. Many of the interactions appear statistically significant based on the their p-values. However, the sums of squares of the three term interactions are very small when compared to the main effects and first order interactions. So, although several of the three term interactions appear significant, their corresponding small sum of squares indicated that a further breakdown in smaller dfs groups is necessary.

ANOVA table for Blue ISAACA Personality Weights.

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
aliveB	2	43.40954	21.70477	244.8672	0.0000000
aliveR	2	21.87185	10.93593	123.3761	0.0000000
injrdB	2	0.39581	0.19790	2.2327	0.1094348
injrdR	2	9.09885	4.54943	51.3254	0.0000000
Rgoal	2	1.73212	0.86606	9.7707	0.0000829
aliveB:aliveR	4	3.33926	0.83481	9.4181	0.0000004
aliveB:injrdB	4	0.34164	0.08541	0.9636	0.4281349
aliveR:injrdB	4	0.53604	0.13401	1.5119	0.1993006
aliveB:injrdR	4	0.25131	0.06283	0.7088	0.5866090
aliveR:injrdR	4	3.31957	0.82989	9.3626	0.0000005
injrdB:injrdR	4	0.50402	0.12600	1.4215	0.2273816
aliveB:Rgoal	4	6.61769	1.65442	18.6647	0.0000000
aliveR:Rgoal	4	7.01598	1.75399	19.7881	0.0000000
injrdB:Rgoal	4	0.40633	0.10158	1.1460	0.3354920
injrdR:Rgoal	4	2.22261	0.55565	6.2687	0.0000813
aliveB:aliveR:injrdB	8	0.45359	0.05670	0.6397	0.7439938
aliveB:aliveR:injrdR	8	1.17375	0.14672	1.6552	0.1100854
aliveB:injrdB:injrdR	8	0.19943	0.02493	0.2812	0.9717083
aliveR:injrdB:injrdR	8	0.26715	0.03339	0.3767	0.9323231
aliveB:aliveR:Rgoal	8	1.50096	0.18762	2.1167	0.0349148
aliveB:injrdB:Rgoal	8	0.90938	0.11367	1.2824	0.2531689
aliveR:injrdB:Rgoal	8	0.76671	0.09584	1.0812	0.3768204
aliveB:injrdR:Rgoal	8	1.51149	0.18894	2.1315	0.0335946
aliveR:injrdR:Rgoal	8	1.44087	0.18011	2.0319	0.0434300
injrdB:injrdR:Rgoal	8	1.01951	0.12744	1.4377	0.1813114
aliveB:aliveR:injrdB:injrdR	16	1.97597	0.12350	1.3933	0.1453162
aliveB:aliveR:injrdB:Rgoal	16	1.29973	0.08123	0.9165	0.5508866
aliveB:aliveR:injrdR:Rgoal	16	1.77238	0.11077	1.2497	0.2311369
aliveB:injrdB:injrdR:Rgoal	16	1.31112	0.08194	0.9245	0.5416891
aliveR:injrdB:injrdR:Rgoal	16	1.33063	0.08316	0.9382	0.5260017
aliveB:aliveR:injrdB:injrdR:Rgoal	32	3.06920	0.09591	1.0821	0.3568790
Residuals	243	21.53926	0.08864		

Table 13. ANOVA table of the Blue ISAACA Personality Weights.

a. Yates' Algorithm

As conducted earlier, Yates' Algorithm was implemented to justify the assumption of using the three term interactions as noise. In the Table 14, it is clear that the three term interactions have only a small number of dfs that appear significant. Also, the three term interactions have a small sum of squares when compared to the main effects and first order interactions. The main effects and first order interactions represent approximately 71% of the total sum of squares.

Blue ISAACA Personality Weights
a=aliveB b=aliveR c=injrdB d=injrdR e=Rgoal
L=Linear term Q=Quadratic Term

ANOVA	SS	df	Mean Square	Fo	Pr(F)
a=aL+aQ	**43.409539**	**2**	**21.70477**	**244.86428**	5.762E-59
aL	15.977789	1	15.977789	180.25484	4.081E-31
aQ	27.43175	1	27.43175	309.47372	3.115E-45
b=bL+bQ	**21.871852**	**2**	**10.935926**	**123.37462**	1.046E-37
bL	16.565137	1	16.565137	186.88106	6.119E-32
bQ	5.3067146	1	5.3067146	59.86817	2.708E-13
c=cL+cQ	**0.3958069**	**2**	**0.1979035**	**2.2326654**	0.1094377
cL	0.3933964	1	0.3933964	4.4381358	0.0361701
cQ	0.0024106	1	0.0024106	0.0271951	0.8691525
d=dL+dQ	**9.0988545**	**2**	**4.5494273**	**51.324766**	2.552E-19
dL	5.2417179	1	5.2417179	59.134904	3.653E-13
dQ	3.8571366	1	3.8571366	43.514628	2.608E-10
e=eL+eQ	**1.7321218**	**2**	**0.8660609**	**9.7705425**	8.293E-05
eL	1.6814201	1	1.6814201	18.969089	1.96E-05
eQ	0.0507017	1	0.0507017	0.5719956	0.4501996
ab	**3.3392577**	**4**	**0.8348144**	**9.4180327**	4.297E-07
axbL=abLxL+abQxL	1.1367742	2	0.5683871	6.4123094	0.0019327
axbQ=abLxQ +abQxQ	2.2024835	2	1.1012417	12.423756	7.291E-06
ac	**0.3416375**	**4**	**0.0854094**	**0.9635535**	0.4281414
axcL=acLxL+acQxL	0.0304858	2	0.0152429	0.171964	0.8421118
axcQ=acLxQ +acQxQ	0.3111517	2	0.1555759	1.7551429	0.175067
ad	**0.2513069**	**4**	**0.0628267**	**0.7087852**	0.5866148

axdL=adLxL+adQxL	0.2451901	2	0.1225951	1.383067	0.2527753
axdQ=adLxQ +adQxQ	0.0061168	2	0.0030584	0.0345035	0.9660897
ae	**6.6176916**	**4**	**1.6544229**	**18.664518**	2.156E-13
axeL=aeLxL+aeQxL	6.4166258	2	3.2083129	36.194866	1.743E-14
axeQ=aeLxQ + aeQxQ	0.2010658	2	0.1005329	1.1341705	0.3233857
bc	**0.5360444**	**4**	**0.1340111**	**1.511858**	0.199306
bxcL=bcLxL+bcQxL	0.1791384	2	0.0895692	1.010483	0.3655676
bxcQ=bcLxQ + bcQxQ	0.3569059	2	0.178453	2.013233	0.1357778
bd	**3.3195681**	**4**	**0.829892**	**9.3625002**	4.708E-07
bxdL=bdLxL+bdQxL	0.2963237	2	0.1481618	1.6715008	0.1901185
bxdQ=bdLxQ + bdQxQ	3.0232444	2	1.5116222	17.0535	1.174E-07
be	**7.0159752**	**4**	**1.7539938**	**19.787836**	4.085E-14
bxeL=beLxL+beQxL	6.3148404	2	3.1574202	35.620715	2.714E-14
bxeQ="beLxQ" + "beQxQ"	0.7011348	2	0.3505674	3.9549573	0.0204055
cd	**0.5040184**	**4**	**0.1260046**	**1.4215321**	0.2273873
cxdL=cdLxL+cdQxL	0.2709382	2	0.1354691	1.5283065	0.2189801
cxdQ=cdLxQ+cdQxQ	0.2330803	2	0.1165401	1.3147578	0.2704427
ce	**0.4063282**	**4**	**0.101582**	**1.1460068**	0.3354984
cxeL=ceLxL+ceQxL	0.3972108	2	0.1986054	2.2405842	0.1085901
cxeQ=ceLxQ + ceQxQ	0.0091174	2	0.0045587	0.0514293	0.9498811
de	**2.2226053**	**4**	**0.5556513**	**6.2686297**	8.134E-05
dxeL=deLxL+deQxL	1.618775	2	0.8093875	9.1311768	0.0001501
dxeQ=deLxQ +deQxQ	0.6038303	2	0.3019152	3.4060826	0.0347626
abc	**0.453588**	**8**	**0.0566985**	**0.6396491**	0.7440004
abcLxLxL+abcQxLxL	0.0397053	2	0.0198526	0.2239693	0.7995045
abcLxQxL+abcQxQxL	0.3621451	2	0.1810726	2.0427862	0.1318878
abcLxLxQ+abcQxLxQ	0.002054	2	0.001027	0.0115863	0.9884811
abcLxQxQ+abcQxQxQ	0.0496835	2	0.0248418	0.2802545	0.7558353
abd	**1.1737475**	**8**	**0.1467184**	**1.6552171**	0.1100907
abdLxLxL+abdQxLxL	0.3772409	2	0.1886204	2.127938	0.1212964
abdLxQxL+abdQxQxL	0.3083798	2	0.1541899	1.7395072	0.1777864
abdLxLxQ+abdQxLxQ	0.2265372	2	0.1132686	1.2778498	0.2805013
abdLxQxQ+abdQxQxQ	0.2615896	2	0.1307948	1.4755733	0.2306889
abe	**1.5009576**	**8**	**0.1876197**	**2.1166482**	0.0349171
abeLxLxL+abeQxLxL	0.098979	2	0.0494895	0.5583201	0.5729017
abeLxQxL+abeQxQxL	0.8577051	2	0.4288525	4.8381378	0.0087012
abeLxLxQ+abeQxLxQ	0.1596781	2	0.0798391	0.9007114	0.4076325
abeLxQxQ+abeQxQxQ	0.3845954	2	0.1922977	2.1694234	0.1164512
acd	**0.1994315**	**8**	**0.0249289**	**0.281238**	0.9717093
acdLxLxL+acdQxLxL	0.0367429	2	0.0183714	0.207259	0.8129527
acdLxQxL+acdQxQxL	0.0473256	2	0.0236628	0.2669538	0.7659327
acdLxLxQ+acdQxLxQ	0.0371952	2	0.0185976	0.2098105	0.8108845
acdLxQxQ+acdQxQxQ	0.0781679	2	0.0390839	0.4409288	0.6439523
ace	**0.9093763**	**8**	**0.113672**	**1.2824011**	0.2531771

aceLxLxL+aceQxLxL	0.6164994	2	0.3082497	3.4775461	0.0324288
aceLxQxL+aceQxQxL	0.0487133	2	0.0243567	0.2747818	0.7599736
aceLxLxQ+aceQxLxQ	0.0419648	2	0.0209824	0.2367148	0.7893981
aceLxQxQ+aceQxQxQ	0.2021988	2	0.1010994	1.1405616	0.3213445
ade	**1.5114907**	**8**	**0.1889363**	**2.131502**	0.0335968
adeLxLxL+adeQxLxL	0.2740101	2	0.1370051	1.5456347	0.2152649
adeLxQxL+adeQxQxL	0.8065473	2	0.4032737	4.5495676	0.0114879
adeLxLxQ+adeQxLxQ	0.2416405	2	0.1208203	1.3630446	0.2578298
adeLxQxQ+adeQxQxQ	0.1892927	2	0.0946463	1.0677611	0.3453847
bcd	**0.2671472**	**8**	**0.0333934**	**0.3767306**	0.9323254
bcdLxLxL+bcdQxLxL	0.2007543	2	0.1003771	1.1324136	0.3239491
bcdLxQxL+bcdQxQxL	0.0126231	2	0.0063115	0.0712043	0.9312911
bcdLxLxQ+bcdQxLxQ	0.0100119	2	0.0050059	0.056475	0.9451025
bcdLxQxQ+bcdQxQxQ	0.0437579	2	0.021879	0.2468295	0.7814695
bce	**0.7667119**	**8**	**0.095839**	**1.081216**	0.3768296
bceLxLxL+bceQxLxL	0.4754366	2	0.2377183	2.6818401	0.0704628
bceLxQxL+bceQxQxL	0.1889986	2	0.0944993	1.0661025	0.345953
bceLxLxQ+bceQxLxQ	0.0825302	2	0.0412651	0.4655358	0.6283574
bceLxQxQ+bceQxQxQ	0.0197464	2	0.0098732	0.1113856	0.8946394
bde	**1.4408735**	**8**	**0.1801092**	**2.0319177**	0.0434328
bdeLxLxL+bdeQxLxL	0.0976236	2	0.0488118	0.5506749	0.5772783
bdeLxQxL+bdeQxQxL	1.1573945	2	0.5786972	6.528624	0.0017306
bdeLxLxQ+bdeQxLxQ	0.1505932	2	0.0752966	0.849465	0.4289095
bdeLxQxQ+bdeQxQxQ	0.0352622	2	0.0176311	0.1989069	0.8197595
cde	**1.0195053**	**8**	**0.1274382**	**1.4377049**	0.1813184
cdeLxLxL+cdeQxLxL	0.4515981	2	0.2257991	2.5473722	0.0803763
cdeLxQxL+cdeQxQxL	0.380942	2	0.190471	2.1488155	0.1188331
cdeLxLxQ+cdeQxLxQ	0.1686157	2	0.0843078	0.9511264	0.387739
cdeLxQxQ+cdeQxQxQ	0.0183495	2	0.0091747	0.1035057	0.9017106
abcd	**1.9759722**	**16**	**0.1234983**	**1.3932566**	0.1453245
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.05198	4	0.012995	0.1466041	0.9643752
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.4922206	4	0.1230552	1.3882576	0.2385858
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.5840697	4	0.1460174	1.6473085	0.1630272
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.847702	4	0.2119255	2.3908562	0.0514506
abce	**1.2997312**	**16**	**0.0812332**	**0.9164395**	0.5508993
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.1915519	4	0.047888	0.5402526	0.7063061
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.1439315	4	0.0359829	0.4059439	0.8042889
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.4265035	4	0.1066259	1.2029091	0.3101701
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.5377443	4	0.1344361	1.5166526	0.1979063
abde	**1.7723789**	**16**	**0.1107737**	**1.2497031**	0.2311476
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.1776242	4	0.0444061	0.5009708	0.7350496
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.9662207	4	0.2415552	2.7251262	0.0300655
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.1807763	4	0.0451941	0.5098609	0.7285365
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.4477577	4	0.1119394	1.2628545	0.2852385
acde	**1.3111151**	**16**	**0.0819447**	**0.9244663**	0.5417019

LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.9272078	4	0.231802	2.6150943	0.035915
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.0816346	4	0.0204087	0.230242	0.921238
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.0359045	4	0.0089761	0.1012651	0.9819508
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.2663681	4	0.066592	0.7512639	0.558013
bcde	**1.3306334**	**16**	**0.0831646**	**0.9382286**	0.5260146
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.0377298	4	0.0094324	0.1064129	0.980205
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.280817	4	0.0702042	0.7920154	0.5313344
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.161795	4	0.0404487	0.456326	0.7677321
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.5389966	4	0.1347491	1.5201844	0.1968808
abcde	**3.0692011**	**32**	**0.0959125**	**1.0820458**	0.3568963
		Total Sum of Squares			142.604

Table 14. Yates' Algorithm for the Blue ISAACA Personality Weights.

The above results allow for the same reasonable assumptions earlier. The main effects and first order interactions effects are analyzed and the higher order interactions are assumed to be noise. Table 15 is the ANOVA table of the main effects and first order interactions.

```
ANOVA for the Blue ISAACA Personality Weights.
Main Effects and First Order Interactions.

               Df Sum of Sq  Mean Sq  F Value     Pr(F)
       aliveB   2  43.40954 21.70477 227.2826 0.0000000
       aliveR   2  21.87185 10.93593 114.5161 0.0000000
       injrdB   2   0.39581  0.19790   2.0724 0.1271299
       injrdR   2   9.09885  4.54943  47.6396 0.0000000
        Rgoal   2   1.73212  0.86606   9.0690 0.0001384
aliveB:aliveR   4   3.33926  0.83481   8.7418 0.0000009
aliveB:injrdB   4   0.34164  0.08541   0.8944 0.4671621
aliveB:injrdR   4   0.25131  0.06283   0.6579 0.6215769
 aliveB:Rgoal   4   6.61769  1.65442  17.3244 0.0000000
aliveR:injrdB   4   0.53604  0.13401   1.4033 0.2319223
aliveR:injrdR   4   3.31957  0.82989   8.6903 0.0000009
 aliveR:Rgoal   4   7.01598  1.75399  18.3670 0.0000000
injrdB:injrdR   4   0.50402  0.12600   1.3195 0.2618223
 injrdB:Rgoal   4   0.40633  0.10158   1.0637 0.3739994
 injrdR:Rgoal   4   2.22261  0.55565   5.8185 0.0001437
    Residuals 435  41.54112  0.09550
```

Table 15. ANOVA Table of Blue ISAACA Personality Weights.

The above results simplify the analysis somewhat. The two main effects aliveB and aliveR are most significant, as in the previous LC personality results. These two parameters account for 50% of the of the total sum squares. Another finding utilizing Table 14, the quadratic effects have a larger influence in this data set. That is the effects are more nonlinear. However, in the Blue ISAACA data the injrdR parameter is much more significant then in the LC Personality data set. The Rgoal parameter is not nearly as significant, which is similar to the LC Personality data set.

There are a few similar results concerning the first order interactions as well. The aliveB:aliveR and aliveR:Rgoal interactions are significant, as in the LC Personality data case. However, in this data set, the aliveB:Rgoal and the aliveR:injrdR interactions are significant as well. Since these interaction terms have a sum of squares nearly as large as the corresponding main effects, the main effects can not be interpreted independently. The analysis is not clear as to whether the main effects or the interaction terms have more significance. These results will be explored further in the Trellis plots.

b. Fractional Factorial Design

Once again the fractional factorial design results are performed and examined. The intent was to determine if similar results would be reached from a design that required 1/3 the number of simulation runs. Table 16 is the ANOVA table of the fractional design. The results are very similar to the full factorial design. The main effects aliveB and aliveR are most significant. The main effect injrdR is also significant when compared to the other two main effects. It is important to remember that the total sum of squares in the fractional design is much smaller then in the full factorial design.

The interaction terms also show aliveB:Rgoal, aliveR:Rgoal, and aliveR:injrdR as having the significant effects. The fractional design leads to similar conclusions as the full factorial design.

```
ANOVA table for Blue ISAACA Personality Weights.
1/3 fractional Factorial Design.

               Df Sum of Sq  Mean Sq  F Value     Pr(F)
       aliveB   2  15.37417 7.687084 75.02438 0.0000000
       aliveR   2   6.68026 3.340128 32.59897 0.0000000
       injrdB   2   0.02082 0.010409  0.10159 0.9034846
       injrdR   2   2.75421 1.377106 13.44028 0.0000059
        Rgoal   2   1.23151 0.615756  6.00966 0.0033259
aliveB:aliveR   4   0.93056 0.232641  2.27053 0.0660967
aliveB:injrdB   4   0.06681 0.016702  0.16301 0.9566467
aliveB:injrdR   4   0.52742 0.131855  1.28688 0.2795199
 aliveB:Rgoal   4   1.25713 0.314284  3.06734 0.0193857
aliveR:injrdB   4   0.39148 0.097871  0.95520 0.4351543
aliveR:injrdR   4   1.17291 0.293228  2.86185 0.0266575
 aliveR:Rgoal   4   3.31496 0.828740  8.08834 0.0000092
injrdB:injrdR   4   0.71487 0.178718  1.74425 0.1453241
 injrdB:Rgoal   4   0.41861 0.104654  1.02140 0.3995389
 injrdR:Rgoal   4   0.85613 0.214033  2.08892 0.0870026
    Residuals 111  11.37319 0.102461
```

Table 16. ANOVA table for Blue ISAACA Personality Weights using a 1/3 fractional factorial design. In comparison to the full factorial design, the significant effects are the same.

c. Desert Scenario

The desert scenario is analyzed using the same five parameters for the Blue ISAACA Personality Weights parameter set. The intent was to determine if the significant parameters may be globally significant parameters rather than scenario dependent parameters. The same analysis procedure is utilized as previously. The full factorial ANOVA table is examined and then analyzed using Yates' Algorithm. The outcome is nearly identical and therefore the assumption of discounting the higher order interactions still held. The resulting ANOVA in Table 17 is comprised of main effects and first order interactions.

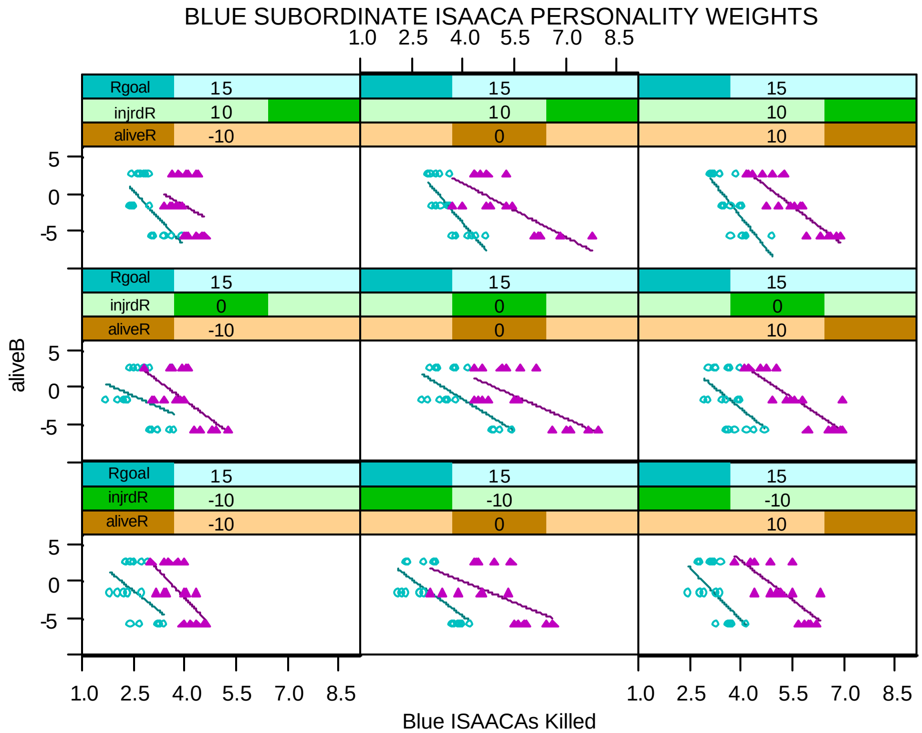
```
ANOVA table for the Desert Scenario.
Main effects and First Order Interactions.

Df Sum of Sq  Mean Sq  F Value     Pr(F)
       aliveB   2  44.22198 22.11099  98.3684 0.0000000
       aliveR   2  76.32491 38.16245 169.7788 0.0000000
       injrdB   2   1.67792  0.83896   3.7324 0.0247050
       injrdR   2   4.12654  2.06327   9.1792 0.0001246
        Rgoal   2  28.58391 14.29196  63.5827 0.0000000
aliveB:aliveR   4  12.24900  3.06225  13.6235 0.0000000
aliveB:injrdB   4   1.65352  0.41338   1.8391 0.1203164
aliveB:injrdR   4   2.24789  0.56197   2.5001 0.0419718
 aliveB:Rgoal   4  32.19237  8.04809  35.8047 0.0000000
aliveR:injrdB   4   2.57538  0.64384   2.8644 0.0230454
aliveR:injrdR   4   3.94242  0.98561   4.3848 0.0017405
 aliveR:Rgoal   4  18.95317  4.73829  21.0799 0.0000000
injrdB:injrdR   4   0.36736  0.09184   0.4086 0.8024856
 injrdB:Rgoal   4   1.58787  0.39697   1.7660 0.1346505
 injrdR:Rgoal   4   2.01289  0.50322   2.2388 0.0640541
    Residuals 435  97.77818  0.22478
```

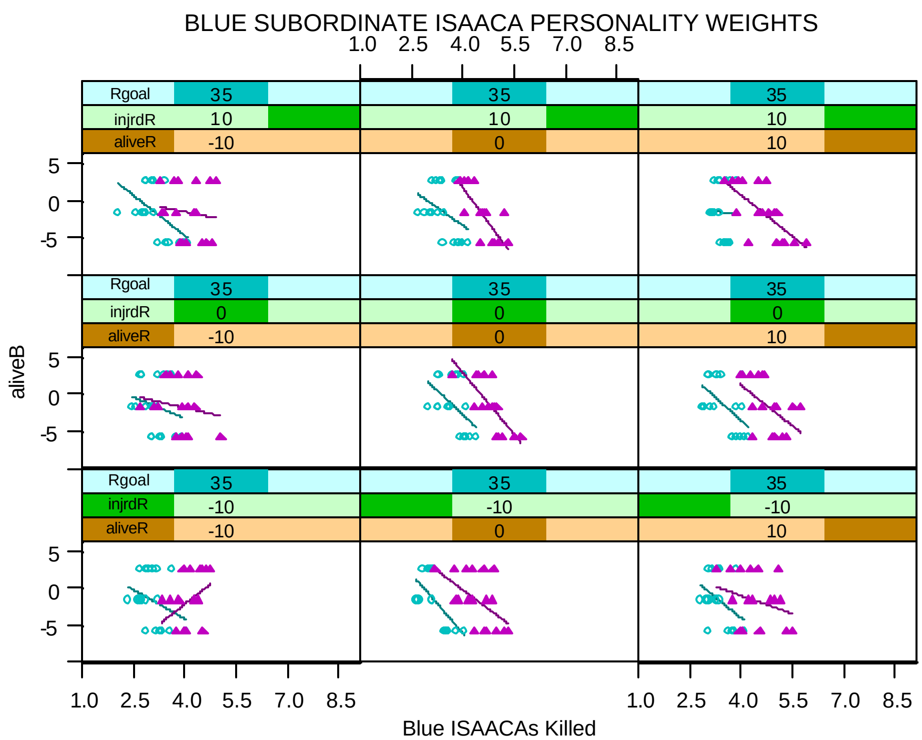
Table 17. ANOVA table for the desert scenario. The main effects and first order interactions are displayed. Overall similar results as in the urban scenario. The most significant change was in the reduction of the injrdR effect and the increase of the Rgoal effect.

The results of this ANOVA are somewhat interesting. The main effects aliveB and aliveR are still the most significant. As in the urban scenario, the interaction terms aliveB:aliveR, aliveB:Rgoal and aliveR:Rgoal are also significant. The interesting point is the shift from injrdR to Rgoal having greater significance. It appears that in the no terrain environment the injured red ISAACAs do not influence the battlefield as much as in an urban environment. It is possible that, in a no terrain environment, the blue ISAACAs can more readily maneuver to avoid the injured red ISAACAs. With a reduced movement and sensor range, the injured red ISAACAs can not stay with the blue forces when they maneuver. The notion of no terrain also explains why the Rgoal parameter increased in significance. There are no obstacles to block or restrict movement, therefore, in the open battlefield, having a strong propensity to move toward the goal can more readily influence the battlefield. This hypothesis will be explored in more detail in the Trellis plot results.

d. Significant Parameters and Interactions

As in the previous section, Trellis plots are used to represent the data from both scenarios. Blue circles indicate the urban scenario and pink triangles indicate the desert scenario. The x-axis is the number of blue ISAACAs killed and the y-axis is the most significant parameter, aliveB. The data is then conditioned on three of the other parameters and displayed in the three frames below. In Figure 17, the injrdB parameter is considered least significant and was removed.


BLUE SUBORDINATE ISAACA PERSONALITY WEIGHTS
Rgoal
injrdR
aliveR
aliveB
Blue ISAACAs Killed


BLUE SUBORDINATE ISAACA PERSONALITY WEIGHTS
Rgoal
injrdR
aliveR
aliveB
Blue ISAACAs Killed

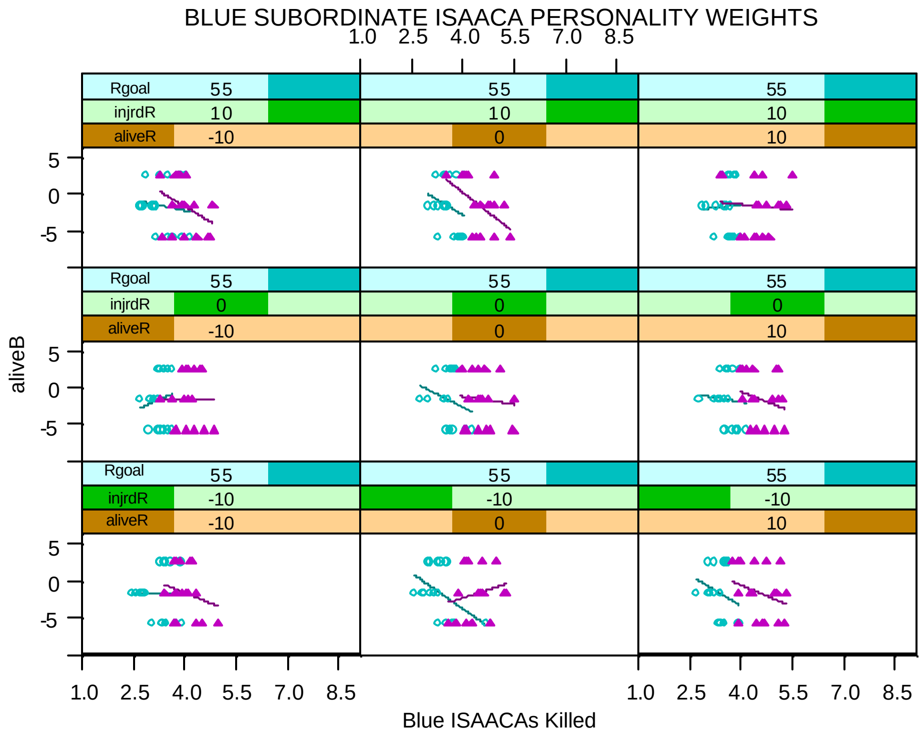


Figure 17: Trellis plot of the Blue ISAACA Personality Weights. The blue circles are the urban scenario data and the pink triangles are the desert scenario data. The columns condition on aliveR, rows condition on injrdB, and frames condition on Rgoal.

As previously noted, the desert scenario has more blue ISAACA average losses then the urban scenario. The no terrain environment has a significant influence on that result, as discussed earlier. The general slopes and spread of both data sets is similar, which corresponds to the results from the ANOVA tables. This similarity indicates that the data, in general, is consistent with previous runs.

The most significant main effects aliveB and aliveR results are apparent in figure 17 by the change in the number of blue ISAACAs killed as the parameter levels change. In the urban scenario, the aliveB setting at the medium level (0) provided the best results. This result held throughout the data. The low setting (-5) was a slight propensity to move away from other alive blue ISAACAs. It proved to be the worse situation throughout. It is interesting that the high level of aliveB resulted in, on average, more blue losses. The desert scenario data had different results. Here the high level of aliveB proved to be the most successful. The removal of terrain seemed to have an impact on the aliveB parameter. The result seems to stress that although force concentration is important, it is not the overriding concern in an urban environment. The desert scenario data reflected that a stronger propensity to move toward other alive blues reduced losses. Force concentration has a greater effect in an open battlefield environment.

The main effect aliveR reflects the same results in both scenarios. Both scenarios resulted in less blue losses when the aliveR parameter is a negative parameter. This result means that propensity to move away or avoid the enemy is more effective. To a military thinker, this avoidance is interpreted as maneuver warfare. Avoiding the frontal assault by maneuver is a fundamental concept of warfare. The Marine Corps stresses the importance of maneuver warfare in the officer training commands [Ref 10].

The main effects injrdR and Rgoal results are more subtle. Although significant, their impact is not as readily discernable. In the urban scenario, the injrdR parameter is more significant then the Rgoal parameter. This can be seen in the data by comparing the corresponding rows. The blue losses are higher when injrdR is at its low value. In the urban scenario, the injured red ISAACAs can still have an impact. This result is possible because the terrain restricts the movement of the alive blue ISAACAs.

The Rgoal parameter for the desert scenario is best examined in the interaction case. This is the interaction terms aliveR:Rgoal. The data reflects more losses when Rgoal is at the low level and less losses when Rgoal is at the high level. The data reflects the notion that if the aliveR is at the low level and Rgoal is at the high level, losses are minimized. In the desert scenario, avoiding the enemy while maintaining an aggressive drive towards the goal kept losses minimal. This leads to the notion of maneuver warfare and maintaining tempo on the battlefield [Ref 10].

The Trellis plots support what is represented in the ANOVA tables. More importantly, they allow for the representation of the ISAACA data in a form that is readable and interpretable. The Trellis plots support the basic purpose of ISAAC to explore the tactical possibilities in combat with a focus on the human characteristics.

4. Mixed Parameters

This data set consisted of mixed parameters. They are specifically chosen to examine the effects on the blue losses when the LC and subordinate ISAACA's propensity to move toward the red goal are varied. Also, the effects of bond and friction are examined. The final parameter is the LC sensor range. The parameters are lcw6, rgoal, bond, friction, and lcsr. The parameter lcw6 is the LC's propensity to move toward the red goal. It is called lcw6 to distinguish it from rgoal, the subordinate's propensity to move toward the red goal. The same analysis methodology is used as in the previous section.

Table 18 is the ANOVA table for the full factorial design of the Mixed Parameters. Once again, a few of the higher order interactions are listed as significant. However, upon examining the sum of squares of the three, four and five term interactions, they account for only 8% of the total sum of squares. This finding indicates that further analysis into the higher order interactions is necessary.

ANOVA table for the Mixed Parameter set.

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
lcw6	2	49.99029	24.99515	3659.827	0.0000000
bond	2	0.09668	0.04834	7.078	0.0010285
frict	2	18.23681	9.11841	1335.131	0.0000000
rgoal	2	0.16490	0.08245	12.072	0.0000100
lcsr	2	9.43791	4.71896	690.957	0.0000000
lcw6:bond	4	0.82582	0.20646	30.230	0.0000000
lcw6:frict	4	1.37920	0.34480	50.486	0.0000000
bond:frict	4	0.31281	0.07820	11.451	0.0000000
lcw6:rgoal	4	0.34327	0.08582	12.566	0.0000000
bond:rgoal	4	0.15441	0.03860	5.652	0.0002294
frict:rgoal	4	0.78903	0.19726	28.883	0.0000000
lcw6:lcsr	4	4.54907	1.13727	166.521	0.0000000
bond:lcsr	4	1.03565	0.25891	37.911	0.0000000
frict:lcsr	4	0.34319	0.08580	12.563	0.0000000
rgoal:lcsr	4	0.21168	0.05292	7.749	0.0000068
lcw6:bond:frict	8	1.37043	0.17130	25.082	0.0000000
lcw6:bond:rgoal	8	0.33635	0.04204	6.156	0.0000003
lcw6:frict:rgoal	8	0.25823	0.03228	4.726	0.0000211
bond:frict:rgoal	8	0.32750	0.04094	5.994	0.0000005
lcw6:bond:lcsr	8	0.66936	0.08367	12.251	0.0000000
lcw6:frict:lcsr	8	0.67598	0.08450	12.372	0.0000000
bond:frict:lcsr	8	1.77084	0.22135	32.411	0.0000000
lcw6:rgoal:lcsr	8	0.06765	0.00846	1.238	0.2773497
bond:rgoal:lcsr	8	0.04745	0.00593	0.868	0.5438077
frict:rgoal:lcsr	8	0.23648	0.02956	4.328	0.0000679
lcw6:bond:frict:rgoal	16	0.38494	0.02406	3.523	0.0000105
lcw6:bond:frict:lcsr	16	0.98725	0.06170	9.035	0.0000000
lcw6:bond:rgoal:lcsr	16	0.16052	0.01003	1.469	0.1117989
lcw6:frict:rgoal:lcsr	16	0.15115	0.00945	1.383	0.1503451
bond:frict:rgoal:lcsr	16	0.27325	0.01708	2.501	0.0014717
lcw6:bond:frict:rgoal:lcsr	32	0.21501	0.00672	0.984	0.4971522
Residuals	243	1.65959	0.00683		

Table 18. ANOVA table for the Mixed Parameters.

a. Yates' Algorithm

Yates' Algorithm is performed as previously. In the Table 19, the breakdown of the higher order interactions yields results as in the previous section. There are only a small number of dfs in each of the higher order interaction terms that are listed as significant. This fact, combined with the fact that the sum of squares percentage is negligible, leads to the assumption that was previously stated. The higher order interaction effects will assumed to be noise and the ANOVA table recalculated.

Transformed Mixed Parameters

a=lcw6 b=bond c=frict d=rgoal e=lcsr

L=Linear Term Q=Quadratic Term

ANOVA	SS	df	mean square	Fo	Pr(F)
a=aL+aQ	**49.990293**	**2**	**24.995146**	**3659.6115**	3.94E-182
aL	42.67916	1	42.67916	6248.7789	2.32E-175
aQ	7.3111332	1	7.3111332	1070.4441	5.21E-91
b=bL+bQ	**0.0966819**	**2**	**0.048341**	**7.0777401**	0.0010289
bL	0.0698525	1	0.0698525	10.227305	0.0015676
bQ	0.0268294	1	0.0268294	3.9281754	0.0486102
c=cL+cQ	**18.236812**	**2**	**9.118406**	**1335.0521**	8.55E-132
cL	14.341745	1	14.341745	2099.8163	1.45E-121
cQ	3.8950666	1	3.8950666	570.28794	1.1E-65
d=dL+dQ	**0.1648991**	**2**	**0.0824496**	**12.071678**	1.004E-05
dL	0.1269468	1	0.1269468	18.586648	2.361E-05
dQ	0.0379523	1	0.0379523	5.5567073	0.0192039
e=eL+eQ	**9.4379143**	**2**	**4.7189572**	**690.91613**	5.47E-101
eL	9.3148691	1	9.3148691	1363.8168	1.18E-101
eQ	0.1230452	1	0.1230452	18.015408	3.12E-05
ab	**0.8258246**	**4**	**0.2064561**	**30.22784**	2.027E-20
axbL=abLxL+abQxL	0.5438571	2	0.2719286	39.813844	1.106E-15
axbQ=abLxQ +abQxQ	0.2819675	2	0.1409837	20.641837	5.252E-09
ac	**1.3791999**	**4**	**0.3448**	**50.48316**	6.803E-31
axcL=acLxL+acQxL	0.9876888	2	0.4938444	72.305182	2.297E-25
axcQ=acLxQ +acQxQ	0.3915111	2	0.1957556	28.661138	6.672E-12

ad	**0.3432731**	**4**	**0.0858183**	**12.564902**	2.624E-09
axdL=adLxL+adQxL	0.328052	2	0.164026	24.01552	3.038E-10
axdQ=adLxQ +adQxQ	0.0152211	2	0.0076106	1.1142841	0.3298209
ae	**4.5490743**	**4**	**1.1372686**	**166.51077**	2.175E-68
axeL=aeLxL+aeQxL	4.4962233	2	2.2481116	329.15251	6.827E-70
axeQ=aeLxQ + aeQxQ	0.0528511	2	0.0264255	3.8690377	0.0221767
bc	**0.3128112**	**4**	**0.0782028**	**11.449896**	1.569E-08
bxcL=bcLxL+bcQxL	0.2631549	2	0.1315774	19.264632	1.714E-08
bxcQ=bcLxQ + bcQxQ	0.0496563	2	0.0248281	3.63516	0.0278244
bd	**0.1544051**	**4**	**0.0386013**	**5.6517245**	0.0002295
bxdL=bdLxL+bdQxL	0.1020984	2	0.0510492	7.4742632	0.0007078
bxdQ=bdLxQ + bdQxQ	0.0523067	2	0.0261533	3.8291858	0.0230501
be	**1.0356542**	**4**	**0.2589135**	**37.908278**	1.236E-24
bxeL=beLxL+beQxL	1.0010166	2	0.5005083	73.280867	1.248E-25
bxeQ="beLxQ" + "beQxQ"	0.0346375	2	0.0173188	2.5356893	0.0813014
cd	**0.7890263**	**4**	**0.1972566**	**28.880906**	1.205E-19
cxdL=cdLxL+cdQxL	0.773778	2	0.386889	56.645531	6.41E-21
cxdQ=cdLxQ+cdQxQ	0.0152484	2	0.0076242	1.1162803	0.3291691
ce	**0.3431939**	**4**	**0.0857985**	**12.562003**	2.636E-09
cxeL=ceLxL+ceQxL	0.313555	2	0.1567775	22.954243	7.392E-10
cxeQ=ceLxQ + ceQxQ	0.029639	2	0.0148195	2.1697621	0.1164124
de	**0.2116789**	**4**	**0.0529197**	**7.7481298**	6.831E-06
dxeL=deLxL+deQxL	0.205415	2	0.1027075	15.0377	6.964E-07
dxeQ=deLxQ +deQxQ	0.0062639	2	0.003132	0.4585596	0.6327395
abc	**1.3704269**	**8**	**0.1713034**	**25.08102**	5.151E-28
abcLxLxL+abcQxLxL	0.829453	2	0.4147265	60.7213	4.104E-22
abcLxQxL+abcQxQxL	0.1651874	2	0.0825937	12.09278	9.849E-06
abcLxLxQ+abcQxLxQ	0.2705904	2	0.1352952	19.808962	1.073E-08
abcLxQxQ+abcQxQxQ	0.1051962	2	0.0525981	7.7010365	0.0005717
abd	**0.3363461**	**8**	**0.0420433**	**6.1556761**	3.111E-07
abdLxLxL+abdQxLxL	0.1929016	2	0.0964508	14.121643	1.578E-06
abdLxQxL+abdQxQxL	0.0104938	2	0.0052469	0.7682134	0.4649642
abdLxLxQ+abdQxLxQ	0.0851946	2	0.0425973	6.2367952	0.0022836
abdLxQxQ+abdQxQxQ	0.0477561	2	0.023878	3.4960527	0.0318506
abe	**0.6693646**	**8**	**0.0836706**	**12.25045**	1.047E-14
abeLxLxL+abeQxLxL	0.486552	2	0.243276	35.618743	2.718E-14
abeLxQxL+abeQxQxL	0.1541113	2	0.0770556	11.281938	2.064E-05
abeLxLxQ+abeQxLxQ	0.0176307	2	0.0088154	1.2906823	0.276962
abeLxQxQ+abeQxQxQ	0.0110706	2	0.0055353	0.8104386	0.4458612
acd	**0.2582265**	**8**	**0.0322783**	**4.72596**	2.107E-05
acdLxLxL+acdQxLxL	0.1075	2	0.05375	7.8696915	0.0004879
acdLxQxL+acdQxQxL	0.0038342	2	0.0019171	0.280688	0.7555085
acdLxLxQ+acdQxLxQ	0.1029145	2	0.0514573	7.5340066	0.0006691
acdLxQxQ+acdQxQxQ	0.0439777	2	0.0219889	3.219454	0.0416881

ace	**0.6759786**	**8**	**0.0844973**	**12.371496**	7.569E-15
aceLxLxL+aceQxLxL	0.5010176	2	0.2505088	36.677719	1.202E-14
aceLxQxL+aceQxQxL	0.1560349	2	0.0780174	11.422757	1.814E-05
aceLxLxQ+aceQxLxQ	0.0159185	2	0.0079592	1.1653359	0.3135543
aceLxQxQ+aceQxQxQ	0.0030076	2	0.0015038	0.2201736	0.8025394
ade	**0.0676464**	**8**	**0.0084558**	**1.2380389**	0.2773908
adeLxLxL+adeQxLxL	0.0506221	2	0.0253111	3.7058644	0.0259789
adeLxQxL+adeQxQxL	0.0135111	2	0.0067555	0.9890962	0.3734049
adeLxLxQ+adeQxLxQ	0.0006672	2	0.0003336	0.0488417	0.9523413
adeLxQxQ+adeQxQxQ	0.0028461	2	0.0014231	0.2083534	0.812065
bcd	**0.3275037**	**8**	**0.040938**	**5.9938445**	5.009E-07
bcdLxLxL+bcdQxLxL	0.1876828	2	0.0938414	13.739588	2.223E-06
bcdLxQxL+bcdQxQxL	0.0450799	2	0.02254	3.300142	0.0385377
bcdLxLxQ+bcdQxLxQ	0.0381551	2	0.0190776	2.7931995	0.0631921
bcdLxQxQ+bcdQxQxQ	0.0565858	2	0.0282929	4.1424481	0.0170195
bce	**1.7708368**	**8**	**0.2213546**	**32.409165**	2.149E-34
bceLxLxL+bceQxLxL	1.354672	2	0.677336	99.170721	3.244E-32
bceLxQxL+bceQxQxL	0.3795553	2	0.1897777	27.785895	1.357E-11
bceLxLxQ+bceQxLxQ	0.0340596	2	0.0170298	2.4933805	0.0847422
bceLxQxQ+bceQxQxQ	0.0025498	2	0.0012749	0.1866644	0.829841
bde	**0.0474454**	**8**	**0.0059307**	**0.8683271**	0.5438513
bdeLxLxL+bdeQxLxL	0.0356032	2	0.0178016	2.6063813	0.0758635
bdeLxQxL+bdeQxQxL	0.0037799	2	0.00189	0.2767136	0.7585103
bdeLxLxQ+bdeQxLxQ	0.0064795	2	0.0032398	0.4743439	0.6228682
bdeLxQxQ+bdeQxQxQ	0.0015828	2	0.0007914	0.1158695	0.8906406
cde	**0.236478**	**8**	**0.0295598**	**4.3279283**	6.796E-05
cdeLxLxL+cdeQxLxL	0.2018648	2	0.1009324	14.777807	8.777E-07
cdeLxQxL+cdeQxQxL	0.0120867	2	0.0060434	0.8848258	0.4141117
cdeLxLxQ+cdeQxLxQ	0.0045184	2	0.0022592	0.3307773	0.7186881
cdeLxQxQ+cdeQxQxQ	0.018008	2	0.009004	1.3183029	0.2694959
abcd	**0.3849396**	**16**	**0.0240587**	**3.5225075**	1.051E-05
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.1514207	4	0.0378552	5.542485	0.0002758
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.1158951	4	0.0289738	4.2421348	0.00245
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.0781622	4	0.0195406	2.8609886	0.0241135
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.0394616	4	0.0098654	1.4444216	0.2199564
abce	**0.9872496**	**16**	**0.0617031**	**9.0341289**	2.526E-17
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.6044465	4	0.1511116	22.124688	1.37E-15
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.3564056	4	0.0891014	13.045593	1.222E-09
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.0141681	4	0.003542	0.5185979	0.7221385
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.0122294	4	0.0030574	0.4476372	0.7740725
abde	**0.1605216**	**16**	**0.0100326**	**1.4689018**	0.1118331
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.0436587	4	0.0109147	1.59805	0.1754597
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.0602328	4	0.0150582	2.204716	0.0691054
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.0279782	4	0.0069945	1.0240922	0.3954353
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.0286518	4	0.007163	1.0487489	0.3826777

acde	**0.1511474**	**16**	**0.0094467**	**1.3831202**	0.1503863
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.0623972	4	0.0155993	2.2839398	0.0609764
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.0720259	4	0.0180065	2.6363807	0.0347031
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.005424	4	0.001356	0.1985356	0.9389698
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.0113002	4	0.0028251	0.4136249	0.7987553
bcde	**0.2732497**	**16**	**0.0170781**	**2.5004549**	0.0014727
LxLxLxL+QxLxLxL+LxQxLxL+QxQxLxL	0.0842741	4	0.0210685	3.0847051	0.0167303
LxLxQxL+QxLxQxL+LxQxQxL+QxQxQxL	0.0927336	4	0.0231834	3.394348	0.0100481
LxLxLxQ+QxLxLxQ+LxQxLxQ+QxQxLxQ	0.044437	4	0.0111092	1.6265362	0.1681683
LxLxQxQ+QxLxQxQ+LxQxQxQ+QxQxQxQ	0.048893	4	0.0122233	1.7896426	0.1315123
abcde	**0.2150115**	**32**	**0.0067191**	**0.9837641**	0.4972397
					97.4628

Table 19. ANOVA table for Mixed Parameters utilizing Yates' Algorithm.

```
ANOVA table for Mixed Parameters.
Main Effects and First Order Interactions.

              Df Sum of Sq  Mean Sq  F Value     Pr(F)
       lcw6   2  49.99029 24.99515 1133.541 0.0000000
       bond   2   0.09668  0.04834    2.192 0.1128935
      frict   2  18.23681  9.11841  413.524 0.0000000
      rgoal   2   0.16490  0.08245    3.739 0.0245425
       lcsr   2   9.43791  4.71896  214.007 0.0000000
  lcw6:bond   4   0.82582  0.20646    9.363 0.0000003
 lcw6:frict   4   1.37920  0.34480   15.637 0.0000000
 lcw6:rgoal   4   0.34327  0.08582    3.892 0.0040626
  lcw6:lcsr   4   4.54907  1.13727   51.576 0.0000000
 bond:frict   4   0.31281  0.07820    3.547 0.0073216
 bond:rgoal   4   0.15441  0.03860    1.751 0.1378827
  bond:lcsr   4   1.03565  0.25891   11.742 0.0000000
frict:rgoal   4   0.78903  0.19726    8.946 0.0000006
 frict:lcsr   4   0.34319  0.08580    3.891 0.0040688
 rgoal:lcsr   4   0.21168  0.05292    2.400 0.0493969
  Residuals 435   9.59196  0.02205
```

Table 20. ANOVA table for Mixed Parameters. The main effects and first order interactions are displayed.

With the assumption that higher order interactions can be interpreted as noise, the ANOVA in Table 20 reflects the main effects and the first order interactions. Based on the results above, the main effects: lcw6, frict, and lcsr account for approximately 90% of the total sum of squares. The interaction term lcw6:lcsr also seemed to have some bearing on the results. The significance of the main effect, the LC's propensity to move toward the red goal (lcw6) supports the results found earlier in the LC Personality Weight data set. Also, the subordinate ISAACA's propensity to move toward the red goal (rgoal) support the results found in the Blue ISAACA Personality Weights data set. This result is that the LCs propensity to move toward the goal is much more significant than the subordinate propensity to move toward the red goal. The lcw6 and the lcsr effects seem to reflect an importance of the LC having the ability to sense the local environment. The friction level seemed to heavily influence the blue losses as well. These parameters will be discussed more in the significant parameters section.

b. Fractional Factorial Design

A one-third fractional factorial design is conducted with this data set as well. The ANOVA in Table 21 reflects the results of the fractional design. Again, similar conclusions are drawn from the fractional design as in the full factorial design. The main effects lcw6, frict, and lcsr are the most significant. The interaction term lcw6:lcsr can be considered influential as well.

```
ANOVA table for the Mixed Parameters.
1/3 Fractional Factorial Design
```

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
lcw6	2	15.48003	7.740017	310.6631	0.0000000
bond	2	0.02462	0.012309	0.4940	0.6114890
frict	2	6.71150	3.355751	134.6907	0.0000000
rgoal	2	0.18914	0.094570	3.7958	0.0254358
lcsr	2	3.04096	1.520481	61.0280	0.0000000
lcw6:bond	4	0.11288	0.028220	1.1327	0.3448893
lcw6:frict	4	0.62055	0.155138	6.2268	0.0001474
lcw6:rgoal	4	0.52032	0.130079	5.2210	0.0006846
lcw6:lcsr	4	1.81943	0.454857	18.2567	0.0000000
bond:frict	4	0.14181	0.035453	1.4230	0.2310483
bond:rgoal	4	0.03175	0.007938	0.3186	0.8650009
bond:lcsr	4	0.51537	0.128841	5.1713	0.0007390
frict:rgoal	4	0.43102	0.107756	4.3250	0.0027379
frict:lcsr	4	0.12883	0.032209	1.2928	0.2772508
rgoal:lcsr	4	0.16281	0.040703	1.6337	0.1707869
Residuals	111	2.76551	0.024915		

Table 21. ANOVA table for the Mixed Parameters using a 1/3 fractional factorial design.

c. Desert Scenario

The desert scenario is run using the same set of mixed parameters. The same analysis procedures are applied and displayed in the resulting ANOVA in Table 22. The results are very similar to the urban scenario in regards to the lcw6, frict, and lcsr significance. The interaction term lcw6:lcsr is also very significant. The interesting change concerned the increased significance of the main effect bond and the increased significance of the bond:frict interaction term. The data implies that in an open battlefield, a subordinate ISAACA's propensity to stay close to the LC (bond), and the subordinate's ability to listen to the LC (friction) have a greater affect on the blue losses. This result will be discussed more in the next section.

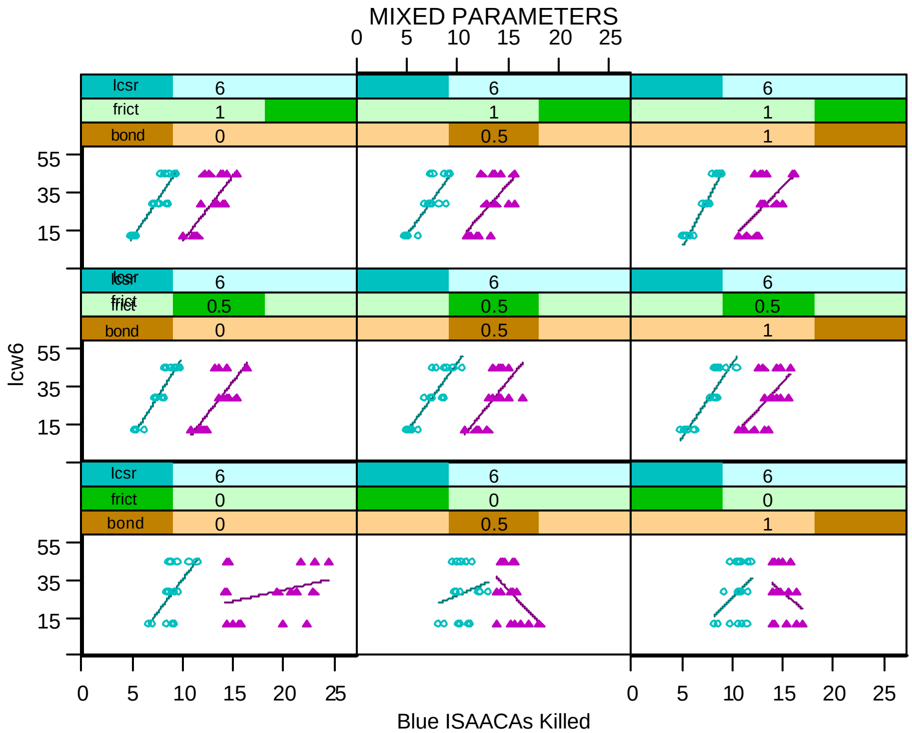
ANOVA for the Desert Scenario.
Main Effects and First Order Interactions.

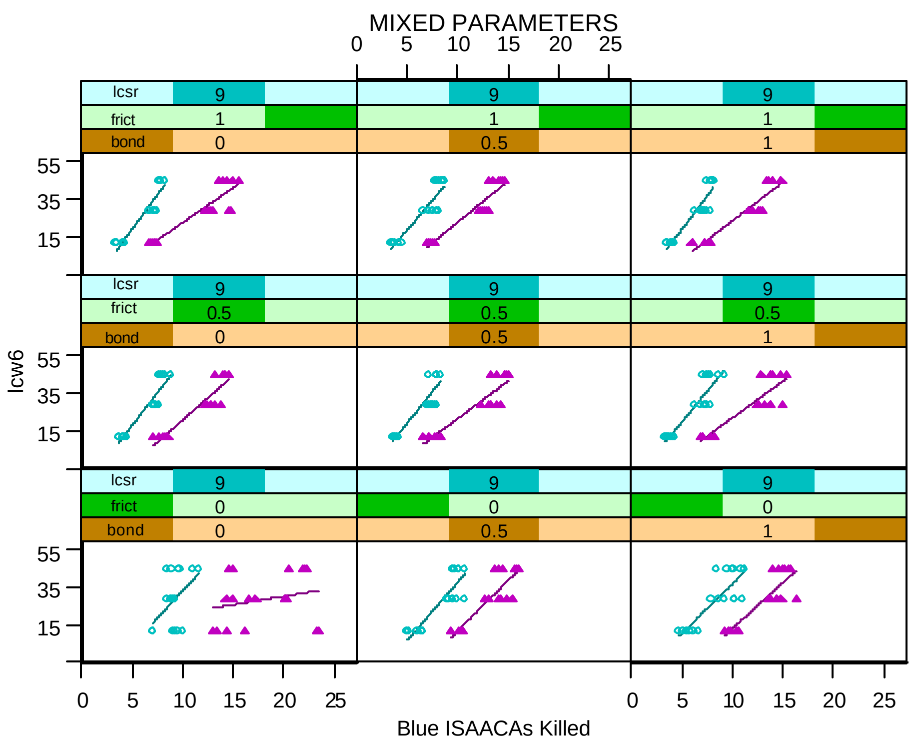
	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
lcw6	2	71.41087	35.70544	948.4457	0.0000000
bond	2	5.38189	2.69095	71.4798	0.0000000
frict	2	22.80604	11.40302	302.8992	0.0000000
rgoal	2	1.28031	0.64016	17.0045	0.0000001
lcsr	2	21.71735	10.85868	288.4397	0.0000000
lcw6:bond	4	0.82909	0.20727	5.5058	0.0002482
lcw6:frict	4	4.53656	1.13414	30.1263	0.0000000
lcw6:rgoal	4	0.32843	0.08211	2.1811	0.0702486
lcw6:lcsr	4	25.02346	6.25587	166.1750	0.0000000
bond:frict	4	10.51774	2.62943	69.8458	0.0000000
bond:rgoal	4	1.62026	0.40507	10.7598	0.0000000
bond:lcsr	4	0.84080	0.21020	5.5836	0.0002167
frict:rgoal	4	1.15191	0.28798	7.6495	0.0000058
frict:lcsr	4	0.38557	0.09639	2.5605	0.0380311
rgoal:lcsr	4	0.26218	0.06555	1.7411	0.1399006
Residuals	435	16.37612	0.03765		

Table 22. ANOVA table for desert scenario with the Mixed Parameter set.

d. Significant Parameters and Interactions

Below are the Trellis plots of the data from the urban scenario and the desert scenario. The x-axis is the number of blue ISAACAs killed and the y-axis is the first parameter, lcw6. The data is then conditioned on three of the other parameters and displayed in Figure 18.


MIXED PARAMETERS
lcsr
frict
bond
6
1
0
0.5
1
lcw6
55
35
15
0
5
10
15
20
25
Blue ISAACAs Killed


MIXED PARAMETERS
lcsr
frict
bond
9
1
0
0.5
1
lcw6
55
35
15
0
5
10
15
20
25
Blue ISAACAs Killed

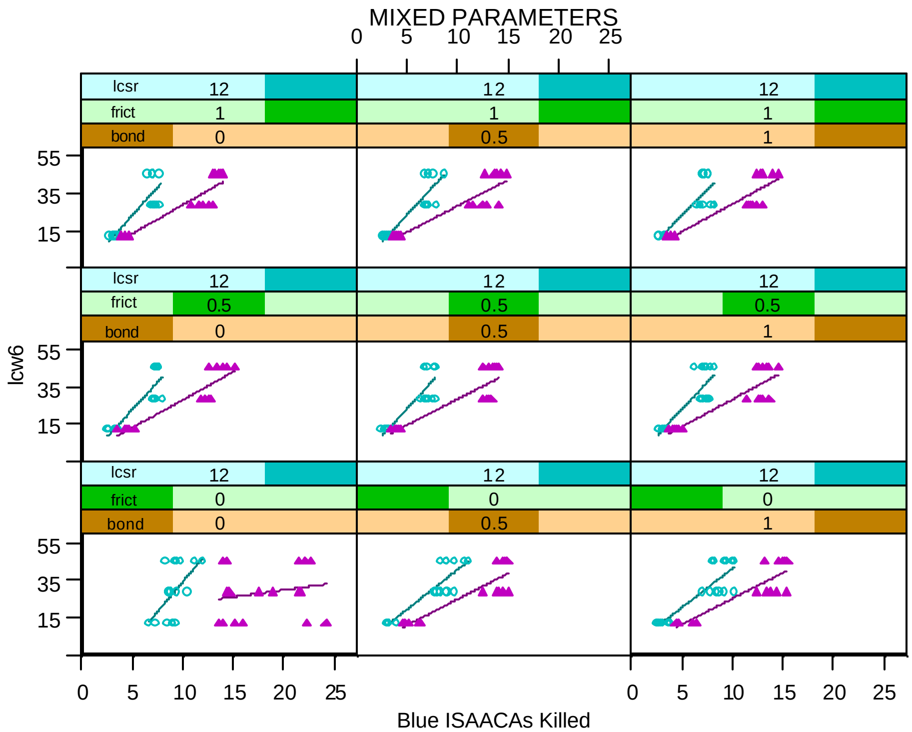


Figure 18: Trellis plots of the Mixed Parameters from the urban scenario data and the desert scenario data.

The desert scenario data is similar to previous results in that the average number of blue losses is greater than in the urban scenario data. The significance of the main effects can be readily interpreted as well. In general, the data reflects that when lcw6 is at the low level (15) the number of blue losses is kept to a minimum. The increasing slope of the data indicates the effect of a low lcw6 weight. This supports the results earlier that the LC's propensity to move toward the red goal should be weighted low with regards to the other personality parameters. This scenario seems to provide the best results. This scenario can be interpreted by acknowledging that the LC needs to consider moving away from the enemy a higher decision priority than moving towards the objective. As in previous results, the subordinate ISAACA's propensity to move toward the red goal is not as significant an effect as the LC's propensity. The LC should be tasked with this decision and the subordinates should concern themselves with other elements of the battlefield. The commanders intent drives the mission [Ref 11].

The bond and friction results are quite interesting. The effect of bond alone proved not to be as significant as initially assumed. This finding is a bit surprising. The bond significance increases in the desert scenario. The bond seems to be more of an influence when the lcw6 weight is low. An LC that maneuvered more and had a higher bond with his unit generally had reduced losses.

However, the friction effect is significant in both scenarios. The ability of the subordinates to listen to the LC is reflected in the data. A high friction level (zero) corresponds directly to increased losses. It is important to remember that the effect of friction can not be interpreted in isolation since the interaction term bond:friction is also significant. In the Figure 18, a low bond (0) and high friction (0) led to high numbers of kills. If the friction was high and the LC propensity to move toward the red goal is high, the losses could be reduced be increasing the bond in a unit. A unit with a good level of unit cohesion, in a high tempo environment, can more efficiently accomplish the mission and overcome the necessity to quickly move towards the objective.

The effect of the LC sensor range is also interesting. In the cases where the lcsr is 9 or 12, the number of losses is reduced. These are the cases when the LC sensor range is at the medium and high level. Also, these cases are when the LC sensor range is greater than that of the subordinate. Again, the effect of the interaction term lcw6:lcsr must be taken into account. With a low lcw6 and a higher lcsr, the number of losses is kept to a minimum. An LC with a greater awareness of the friendly and enemy situation and a propensity to maneuver away from the enemy can effectively reduce the number of losses to his subordinates.

5. Fitting a Poisson Distribution

The data sets are explored to fit the number of blue ISAACAs killed to a Poisson distribution. The chi-square Goodness of Fit test (GOF) in S-Plus is utilized to perform the analysis. Since at each level of the parameters 100 runs were completed at different random initial positions, several of these groups of runs are examined in each data set. Figure 19 is a plot of 100 runs from the LC Personality Weights data set. This is very typical of the data from the Blue ISAACA Personality Weights data as well.

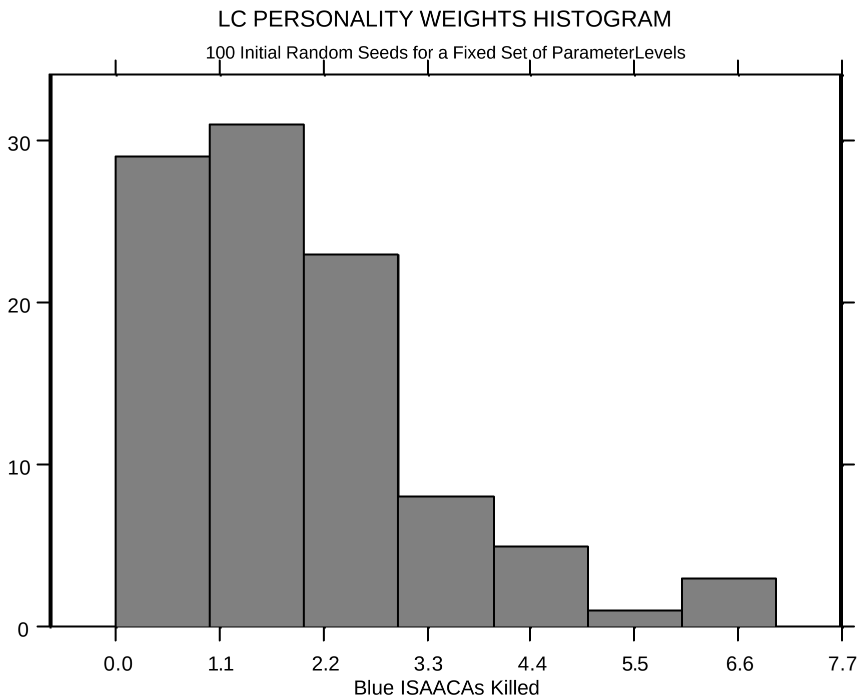


Figure 19: Histogram of 100 runs at constant parameter values from the LC Personality Weights data set.

For the 100 runs, a mean and standard deviation were determined. This information is then used with the frequency of the blue losses. Then using these results, the null hypothesis, that the data is from a Poisson distribution, is tested against the alternative hypothesis that the data is not from a Poisson distribution. The results from the data set above gave a p-value of .3819. Therefore, the null hypothesis is not rejected. Very similar results occurred throughout the LC Personality Weights and the Blue ISAACA Personality Weights data sets. Knowing the mean and hence the variance from a Poisson distribution, helps analysts understand the range of possible outcomes that could occur by chance given only the mean. This could be further explored to perhaps reach an acceptable level of predictability in the ISAAC model.

C. LESSONS LEARNED ON STATISTICAL DESIGNS EXPLORING ISAAC

Several statistical insights are gleaned by looking across the various experimental designs utilized in this thesis. It is necessary to find a balance between the number of factors and levels explored. This balance is to find a factorial design that would effectively explore the response surface of ISAAC with a reasonable number of runs and have a manageable data set for analysis.

Initially, a 5^4 full factorial design was utilized for the command area parameters. Each factor combination was run 100 times for a total of 62500 runs. It was quickly determined that a data set of this size was not manageable by S-Plus. S-Plus is a powerful statistical tool that is designed to handle large data sets, but it could not perform ANOVA calculations on 5 levels and 4 factors. This result lead to a 3^4 full factorial design used for the command area parameters and a 3^5 design for the other parameter sets. The 3^5 design was run 100 times for each factor combination or a total of 24300 runs. The data sets generated from this design were manageable by S-Plus.

The 3^5 full factorial design was used so that nonlinear effects could be explored in ISAAC. The 3^5 full factorial design did show a few areas where the nonlinear effects are significant when compared to the linear effects, as discussed earlier in this section. However, in a 3-level full factorial design, the number of factor combinations quickly increases as the number of factors increase. This result increases the size of the data set.

A 1/3 fractional factorial design was developed to explore the possibilities of increasing the number of factors while keeping the data set manageable for analysis. It is shown that the ISAAC data retains its information value when a 3^{5-1} fractional factorial design is utilized. In a 3^{5-1} fractional factorial design, there are 81 factor combinations vice the 243 factor combinations in a 3^5 full factorial design. This result greatly reduces the number of runs. In future ISAAC designs, the use of fractional designs will allow more factors to be simultaneously explored while producing manageable data sets.

The 2-level factorial design was not explored in this thesis. However, the 2-level factorial design could be an important follow on study. In a 2^5 full factorial design, there are 32 factor combinations. In a 2^{5-1} fractional factorial design, there are 16 combinations. Since the quadratic effects did not dominate in the ISAAC data, it is possible the significant results could still be determined from such a design. The number of necessary runs would be dramatically reduced. This would allow more factors to be simultaneously explored. Also somewhat surprisingly, the major significant effects appeared more linear than nonlinear. This result also provides a strong case for a 2-level design where the number of necessary runs could be greatly reduced.

With a design of experiments developed, it was necessary to have a means of displaying the results. Trellis plots generated by S-Plus provide a means of displaying the results in a clear and insightful manor. The Trellis plot is a powerful tool for presenting data of this type. The effects of multiple variables and their interactions on a response are presented in an interpretable fashion for the user.

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VI. CONCLUSIONS

"The fundamental point is that any military action, by its very nature a complex system, will exhibit messy, unpredictable, and often chaotic behavior that defies orderly, efficient, and precise control."

Command and Control, MCDP 6

Military organizations and military evolutions are complex systems [Ref 11]. A squad-sized combat patrol, changing formation as it moves across the terrain and reacting to the enemy situation, is a complex system [Ref 11]. ISAAC attempts to capture some of this behavior. The intent was to explore ISAAC and to gain some degree of intuitive understanding of the four basic questions stated in the Purpose and Rationale section.

A. CENTRALIZED AND DECENTRALIZED COMMAND AND CONTROL

The intent here is to explore the parameters in the LC command area to determine whether a centralized or decentralized command and control structure is more effective in an urban environment. This question can not be fully explored using the current logic structure in ISAAC's command area. The four LC personality parameters had no significant change in the response data. It is difficult to discern any difference in the response data whether the subordinates are strongly guided or left to a neutral LC movement propensity. Also, the size of the command area had little effect on the time to mission completion (MOE 1) or blue ISAACAs killed (MOE 2). The results are similar in the urban scenario and in the desert scenario. However, a few other parameters that do not directly correlate to the LC's guidance of his subordinates had a significant impact.

The bond and friction parameters are discussed in the next section. The LC sensor range had a significant influence in the number of blue losses. It is seen that by increasing the LC awareness or information on the battlefield two things occurred. First, it reduced the number of losses. Second, it increased the time to mission completion. However, the initial results indicated that there potentially is some optimal tradeoff in the LC sensor range level between time to mission completion and minimizing losses. This is definitely an area for follow on research.

B. LEADERSHIP PERSONALITIES AND POSSIBLE OUTCOMES

The question of the effect of LC personalities and subordinate personalities on the number of losses is explored in depth. For the LC personality weights and the blue ISAACA personality weights, a few parameters had global significance, and a few others were scenario dependent. These global and scenario dependent parameters provided interesting insights into potential combat situations.

The LC's propensities to move toward alive blues, away from alive reds, and toward the red goal are significant in both scenarios. Losses are reduced for an LC with the following characteristics: (1) a strong propensity to move toward friendlies and move away from the enemy, and (2) assigns the mission objective a relative degree of importance without letting the objective dominate his actions. This type of movement propensity directly relates to the concept of maneuver warfare. These parameters are similar in respect to trends in blue ISAACA losses in both scenarios.

The influence of the injured red ISAACAs is more scenario dependent. In the urban environment, the injured red ISAACAs influenced the number of losses of the blue forces. The injured red ISAACA's reduced movement and sensor range does not impact the blue losses in the urban scenario. It is still important for the LC to have a movement propensity to avoid them. In the desert scenario, the influence of the injured red ISAACAs is far less. The blue ISAACAs could maneuver to avoid engagements and the limited ability of the injured red ISAACAs in the open battlefield did not allow them to keep up with the blue ISAACAs. This type of information could influence the decision process of the LC. Knowing that the area you are entering is open terrain with no obstacles could influence the LC to give less importance to the injured than he or she would in the urban environment. It might prompt the LC to weigh more of his decision into maneuvering away from the enemy.

The subordinate blue ISAACA personality results also had some interesting insights. The propensity to move away from red ISAACAs, and the propensity to move toward the other alive blues, are similarly significant in both scenarios. The propensity to avoid the enemy seems globally important. This concept is an underlying theme in many military actions. Therefore, it provides a sanity check in the ISAAC logic structure. The propensity to move toward the red goal, although important, had less of an influence on the subordinate ISAACAs then on the LC. This is an interesting result. This result implies that, to a certain degree, the LC should concern himself or herself with the decisions concerning the mission objective. Although, the subordinates should be aware of and understand the mission, their concern lies primarily in other aspects of the mission.

The propensity to move toward other alive friendlies seems to be more scenario dependent for the subordinates. In the urban scenario, the propensity to move toward other alive blue ISAACAs is more effective if set to zero. At zero, there was no movement propensity toward or away from other friendly ISAACAs. In the desert scenario, it is best to have a strong propensity to move toward other blues. The urban environment causes a concentration of forces due to the terrain. This concentration of forces coupled with a tendency to attract to other friendly forces may not be the best approach in an urban scenario. This result is reflected in the increased blue kills at the higher levels of aliveB. An open battlefield, though, may require a more concentrated fire approach. Therefore, a propensity to attract to other alive friendlies may be more applicable.

The hypothesis generation and the search for answers are exactly the purpose of ISAAC. ISAAC is readily adaptable to allow the user to explore these many options.

C. AFFECT OF FRICTION

Friction, that intangible element that is always present in stressful environments, influences the battlefield in both scenarios. Higher friction levels directly correlate to more blue losses. However, the interesting insight in ISAAC is that the interaction terms helped reduce the effect of friction. Particularly, in the desert scenario, the interaction of bond and friction was prominent. When the friction level was high, a moderate to high level of bond seemed to reduce the effects on losses. A low bond level and a high friction level reflected increased losses in the battlefield. This suggests that a high bond level can compensate some for high friction. In both scenarios, an LC commander, first and foremost, needed a propensity to move away from the enemy. This willingness to maneuver, with a proportional propensity to move toward the red goal, minimized blue losses. In an open battlefield, a strong bond with the unit reduced losses. All of these questions can be further explored and potentially answered using ISAAC.

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VII. RECOMMENDATIONS

The following is a list of recommendations for ISAAC and future research.

- The logic structure in the LC command area should be reviewed. No statistically significant results were determined when varying the parameters incorporated in the LC decision process. The command area logic structure has the potential to allow for insightful studies on centralized and decentralized command and control and should be incorporated in future studies.
- The factorial and fractional factorial design of experiments allows for a structured approach in the exploration of ISAAC. It would benefit the Marine Corps to incorporate these designs at MHPCC. The main effects and first term interactions predominantly influenced the outcomes of the battle. Also, the linear effects were more significant then the quadratic effects. Thus, the fractional design could be utilized at MHPCC. The number of parameters varied could be increased from five to ten and the number of factor combinations could be kept manageable. In a full factorial design, a 3^{10} has 59049 factor combinations. In a 1/3 fractional factorial design, a 3^{10-1} design has 19683 factor combinations. This would allow a more effective exploration of the multi-dimensional response surface.
- The notion of time in mission completion is critical in almost every combat situation. The present statistical package incorporated at MHPCC needs to be

improved to capture the insights of multiple units maneuvering on the battlefield. At present the ability to effectively evaluate time to mission completion as a measure of effectiveness is inadequate. MHPCC should develop a system that allows the user to select from multiple stopping conditions.

- At present, the LC's subordinates start positions are randomly assigned with respect to the LC's start position. This aspect, taken into account with the random initial dispersion, can lead to initial blue losses while the squads organize. I believe it would be better to pre-assign the subordinates and randomly place the squad element at the start of the scenario. This would eliminate unnecessary variance in the results.
- The present ISAAC version does not allow for reinforcements to be entered into the combat scenario. In a limited sense, ISAAC does allow for the reconstitution of some forces. However, this is not fundamentally equivalent to applying a significant force at a critical time in the battle. The use of reinforcements is fundamental to Marine Corps combat tactics. This element should be incorporated in ISAAC to allow for further analysis in this regard.
- The personality weights of the LC and the subordinate ISAACAs are normalized after assigned. The normalizing of these weights complicates the analysis when examining the effects changing a single weight. For analysis purposes, I believe a better technique should be explored for relating the weights.

- Trellis plots provide a means of presenting the effects of many variables. It provides an insightful way to display to effects and complex interactions of multiple variables in a less technical format. The Marine Corps should incorporate the use of Trellis plots in the further development of ISAAC.

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APPENDIX A. DATA INPUT FILE. SOMLC.MHP

```
******************************
* GENERAL BATTLE PARAMETERS
******************************
battle_size       100
*
* initial distribution
*
init_dist         1
R_box_(l,w)        99, 99    0,  0    0,  0    0,  0    0,  0    0,  0
0,  0    0,  0    0,  0    0,  0
RED_cen_(x,y)      50, 50  0,  0   0,  0    0,  0    0,  0    0,  0
0,  0    0,  0    0,  0    0,  0
B_box_(l,w)        15, 15  15, 15   15, 15   0,  0   0,  0    0,  0
0,  0    0,  0    0,  0    0,  0
BLUE_cen_(x,y)     15, 15  15,  15  15, 15   0,  0  0,  0    0,  0
0,  0  0,  0    0,  0  0,  0
B_flag_(x,y)      1,1
R_flag_(x,y)      99,99
termination?      2
move_order?       2
combat_flag?      2
terrain_flag?     1
LOS_flag?         0
*
* fratricide parameters
*
red_frat_flag?    0
blue_frat_flag?   0
red_frat_rad      1
blue_frat_rad     1
red_frat_prob     0.000000
blue_frat_prob    0.000000
*
* reconstitution
*
reconst_flag?     0
RED_recon_time    1000
BLUE_recon_time   1000
*******************************
*   STATISTICS PARAMETERS
*******************************
stat_flag?        0
goal_stat_flag?   0
center_mass_flag? 0
interpoint_flag?  0
entropy_flag?     0
cluster_1_flag?   0
cluster_2_flag?   0
neighbors_flag?   0
*******************************
* RED GLOBAL COMMAND PARAMETERS
```

```
*******************************
RED_global_flag   0
********************************
* BLUE GLOBAL COMMAND PARAMETERS
********************************
BLUE_global_flag   0
******************************
* RED LOCAL COMMAND PARAMETERS
******************************
RED_command_flag  0
******************************
* BLUE LOCAL COMMAND PARAMETERS
******************************
BLUE_command_flag 1
num_BLUE_comdrs   3
B_patch_type      1
B_patch_flag      2
*
* local commander parameters
*
(1)_R_undr_cmd    12
(1)_R_cmnd_rad    1
(1)_R_SENSOR_rng  12
*
* local command personality
*
(1)_w1:alive_B    -1.000000
(1)_w2:alive_R    -10.000000
(1)_w3:injrd_B    -1.000000
(1)_w4:injrd_R    -10.000000
(1)_w5:B_goal     0.000000
(1)_w6:R_goal     15.000000
*
* local command constraints
*
(1)_R_ADV_range   4
(1)_ADVANCE_num   0
(1)_CLUSTER_num   12
(1)_COMBAT_num    -5
*
* local command parameters
*
(1)_R_w_alpha     -1.000000
(1)_R_w_beta      -1.000000
(1)_R_w_delta     -1.000000
(1)_R_w_gamma     -1.000000
*
* global command weights
*
(1)_w_obey_GC_def 0.
(1)_w_help_LC_def 0.
*
* local commander parameters
*
```

```
(2)_R_undr_cmd    12
(2)_R_cmnd_rad    1
(2)_R_SENSOR_rng  12
*
* local command personality
*
(2)_w1:alive_B    -1.000000
(2)_w2:alive_R    -10.000000
(2)_w3:injrd_B    -1.000000
(2)_w4:injrd_R    -10.000000
(2)_w5:B_goal     0.000000
(2)_w6:R_goal     15.000000
*
* local command constraints
*
(2)_R_ADV_range    4
(2)_ADVANCE_num    0
(2)_CLUSTER_num    12
(2)_COMBAT_num     -5
*
* local command parameters
*
(2)_R_w_alpha     -1.000000
(2)_R_w_beta      -1.000000
(2)_R_w_delta     -1.000000
(2)_R_w_gamma     -1.000000
*
* global command weights
*
(2)_w_obey_GC_def 0.
(2)_w_help_LC_def 0.
*
* local command parameters
*
(3)_R_undr_cmd     12
(3)_R_cmnd_rad     1
(3)_R_SENSOR_rng   12
*
* local command personality
*
(3)_w1:alive_B     -1.000000
(3)_w2:alive_R     -10.000000
(3)_w3:injrd_B     -1.000000
(3)_w4:injrd_R     -10.000000
(3)_w5:B_goal      0.000000
(3)_w6:R_goal      15.000000
*
* local command constraints
*
(3)_R_ADV_range     4
(3)_ADVANCE_num     0
(3)_CLUSTER_num     12
(3)_COMBAT_num      -5
*
```

```
* local command parameters
*
(3)_R_w_alpha     -1.000000
(3)_R_w_beta      -1.000000
(3)_R_w_delta     -1.000000
(3)_R_w_gamma     -1.000000
*
* global command weights
*
(3)_w_obey_GC_def 0.
(3)_w_help_LC_def 0.
******************************
* RED ISAACA PARAMETERS
******************************
num_reds          200
squads            1
num_per_squad     200    0    0    0    0    0    0    0    0    0
M_RANGE             1    0    0    0    0    0    0    0    0    0
personality       1
*
* ALIVE personality weights
*
w1_a:R_alive_R     10.000    0.000   0.000   0.000    0.000    0.000
0.000    0.000    1.000    0.000
w2_a:R_alive_B     40.000    0.000   0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w3_a:R_injrd_R     10.000    0.000   0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w4_a:R_injrd_B     40.000    0.000   0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w5_a:R_R_goal       0.000    0.000   0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w6_a:R_B_goal       0.000    0.000   0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
*
* INJURED personality weights
*
w1_i:R_alive_R     10.000    0.000    0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w2_i:R_alive_B     40.000    0.000    0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w3_i:R_injrd_R     10.000    0.000    0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w4_i:R_injrd_B     40.000    0.000    0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w5_i:R_R_goal       0.000    0.000    0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w6_i:R_B_goal       0.000    0.000    0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
*
* ISAACA-LC weights
*
w7:R_loc_comdr    0.000000
w8:R_loc_goal     0.000000
```

```
*
* defense parameters
*
defense_flag      0
alive_strength      1    0    0    0    0    0    0    0    0    0
injrd_strength      1    0    0    0    0    0    0    0    0    0
*
* sensor/fire ranges
*
S_RANGE             6    0    0    0    0    0    0    0    0    0
F_RANGE             4    0    0    0    0    0    0    0    0    0
*
* communications
*
COMM_flag         0
COMM_range        0
COMM_weight       0.000000
*
* movement constraints
*
movement_flag     1
C_RANGE             1    0    0    0    0    0    0    0    0    0
A:ADVANCE_num       0    0    0    0    0    0    0    0    0    0
A:CLUSTER_num       5    0    0    0    0    0    0    0    0    0
A:COMBAT_num      -10    0    0    0    0    0    0    0    0    0
I:ADVANCE_num       0    0    0    0    0    0    0    0    0    0
I:CLUSTER_num       5    0    0    0    0    0    0    0    0    0
I:COMBAT_num      -10    0    0    0    0    0    0    0    0    0
C_RANGE_(m,M)     0,0
A:ADV_(m,M)       0,0
A:CLUS_(m,M)      0,0
A:COMB_(m,M)      0,0
I:ADV_(m,M)       0,0
I:CLUS_(m,M)      0,0
I:COMB_(m,M)      0,0
A:R_R_min_dist     0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
A:R_B_min_dist     0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
A:R_R_goal_min     0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
I:R_R_min_dist     0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
I:R_B_min_dist     0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
I:R_R_goal_min     0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
*
* combat/engagement
*
shot_prob          0.050   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
R_max_eng_num       2    0    0    0    0    0    0    0    0    0
******************************
```

```
* BLUE ISAACA PARAMETERS
******************************
num_blues        39
squads           3
num_per_squad      13   13   13   0    0    0    0    0    0    0
M_RANGE            1    1    1    0    0    0    0    0    0    0
personality      1
*
* ALIVE personality weights
*
w1_a:B_alive_B     -5.000    -5.000   -5.000    0.000    0.000    0.000
0.000    0.000    0.000    0.000
w2_a:B_alive_R     -10.000   -10.000  -10.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w3_a:B_injrd_B     -5.000    -5.000   -5.000    0.000    0.000    0.000
0.000    0.000    0.000    0.000
w4_a:B_injrd_R     -10.000   -10.000  -10.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w5_a:B_B_goal       0.000     0.000     0.000   0.000    0.000    0.000
0.000    0.000    0.000    0.000
w6_a:B_R_goal       35.000    35.000   35.000    0.000    0.000
0.000    0.000    0.000    0.000    0.000
*
* INJURED personality weights
*
w1_i:B_alive_B     -5.000   -5.000    -5.000    0.000   0.000    0.000
0.000    0.000    0.000    0.000
w2_i:B_alive_R     -10.000  -10.000   -10.000   0.000   0.000    0.000
0.000    0.000    0.000    0.000
w3_i:B_injrd_B     -5.000   -5.000    -5.000    0.000   0.000    0.000
0.000    0.000    0.000    0.000
w4_i:B_injrd_R     -10.000  -10.000   -10.000   0.000   0.000    0.000
0.000    0.000    0.000    0.000
w5_i:B_B_goal       0.000     0.000    0.000    0.000   0.000    0.000
0.000    0.000    0.000    0.000
w6_i:B_R_goal      35.000     35.000   35.000   0.000   0.000    0.000
0.000    0.000    0.000    0.000
*
* ISAACA-LC weights
*
w7:B_loc_comdr    0.500000
w8:B_loc_goal     0.300000
*
* defense parameters
*
defense_flag      0
alive_strength      1    0    0    0    0    0    0    0    0    0
injrd_strength      1    0    0    0    0    0    0    0    0    0
*
* sensor/fire ranges
*
S_RANGE             8    8    8    0    0    0    0    0    0    0
F_RANGE             8    8    8    0    0    0    0    0    0    0
*
```

```
* communications
*
COMM_flag         0
COMM_range        0
COMM_weight       0.000000
*
* movement constraints
*
movement_flag     1
C_RANGE             3    3    3    0    0    0    0    0    0    0
A:ADVANCE_num       0    0    0    0    0    0    0    0    0    0
A:CLUSTER_num       12   12   12   0    0    0    0    0    0    0
A:COMBAT_num       -5   -5   -5    0    0    0    0    0    0    0
I:ADVANCE_num       0    0    0    0    0    0    0    0    0    0
I:CLUSTER_num       12   12   12   0    0    0    0    0    0    0
I:COMBAT_num       -5   -5   -5    0    0    0    0    0    0    0
C_RANGE_(m,M)     0,0
A:ADV_(m,M)       0,0
A:CLUS_(m,M)      0,0
A:COMB_(m,M)      0,0
I:ADV_(m,M)       0,0
I:CLUS_(m,M)      0,0
I:COMB_(m,M)      0,0
A:B_B_min_dist     3.000   3.000   3.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
A:B_R_min_dist     0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
A:R_R_goal_min     0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
I:B_B_min_dist     3.000   3.000   3.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
I:B_R_min_dist     0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
I:R_R_goal_min     0.000   0.000   0.000   0.000   0.000   0.000
0.000   0.000   0.000   0.000
*
* combat/engagement
*
shot_prob          0.050   0.050   0.050   0.000   0.000   0.000
0.000   0.000   0.000   0.000
B_max_eng_num       6    6    6    0    0    0    0    0    0    0
******************************
* TERRAIN PARAMETERS
******************************
terrain_num    17
(1)_size       4
(1)_cen_(x,y)  10,10
(2)_size       3
(2)_cen_(x,y)  10,30
(3)_size       1
(3)_cen_(x,y)  11,50
(4)_size       4
(4)_cen_(x,y)  9,75
(5)_size       5
```

```
(5)_cen_(x,y)  35,85
(6)_size       2
(6)_cen_(x,y)  36,65
(7)_size       3
(7)_cen_(x,y)  35,45
(8)_size       4
(8)_cen_(x,y)  35,25
(9)_size       4
(9)_cen_(x,y)  60,10
(10)_size       5
(10)_cen_(x,y)  60,35
(11)_size       3
(11)_cen_(x,y)  60,55
(12)_size       1
(12)_cen_(x,y)  60,75
(13)_size       4
(13)_cen_(x,y)  60,90
(14)_size       5
(14)_cen_(x,y)  85,92
(15)_size       3
(15)_cen_(x,y)  86,70
(16)_size       4
(16)_cen_(x,y)  85,35
(17)_size       5
(17)_cen_(x,y)  85,9
```

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APPENDIX B. S-PLUS CODE: POWER CURVES

<u>S-PLUS CODE</u>:

```
Function(alpha, sigma, trtments, pow)

{
        x←matrix(nrow = 16, ncol = 2)
        j←2
        m←2
        power1←0
        tau←0.5
        for(I in 1:16){
              while(power1<pow){
                    lambda←m/sigma * (tau^2*trtmts)
                          power1←1-pf(qf(1-alpha,trtmts-1,(m*trtmts)
                                -trtmts), trtmts-1,(m*trtmts)-trtmts,lambda)
                    m←m+1
              }
              x[i] ←tau
              x[i,j] ←m
              m←2
              tau←tau+0.1
              power1←0
        }
        x
}
```

The function input parameters are:

alpha – significance level desired by the user.

sigma – variance of data, which is often unknown,

approximated wih mean square error.

pow – power user wishes to terminate at once number of samples is

achieved.

trtmts – number of treatments.

Variables in the code:

tau – user specified detectable departure from the mean.

m – number of samples required to attain the user specified power.

λ - non-centrality parameter used in the calculation of the power.

x – matrix established to record the results.

APPENDIX C. TRELLIS PLOTS OF ISAAC DATA SETS

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